Appendix A

Consent Form for Research

Promoting Conceptual Change in Physics with Models

Researchers: Drs. Elizabeth Charles, Sylvia d'Apollonia, and Ms. Peggy Simpson

You are being asked to participate in a research study conducted by the above named researchers for the purpose of understanding how the use of models, designing and reasoning with models, influences learning in physics. We believe that working with models, and using models to reason and problem solve, will help students gain a deeper understanding of the core principles of physics and ultimately improve their enjoyment and capabilities in physics. To accomplish our goal, we plan to collect information on how you go about the tasks of understanding and problem-solving using different types of science related models (physical models, computer model, etc.).

If you agree to participate in this study there will be five sessions of approximately 60 minutes each. During these sessions, you will work both individually and in small groups, face-to-face and sometimes online. You will build simple physical models using simple materials and use a computer application designed specifically for this project. At the beginning and end of the project you will complete written questionnaires (pretest-posttest); and, at the end of the project, you will produce a small online project with your group. You may be selected for a follow up interview, set at your convenience, and taking no more than 45 minutes. This will be determined on a case-by-case basis.

We would like your permission to collect questionnaire data, and videotape the five sessions mentioned, as well as any follow up interviews assessing your experiences with these models and the related knowledge. All data will be viewed only by the researchers listed above (Elizabeth Charles (Principal Investigator), Silvia d'Apollonia (Biology Instructor), Peggy Simpson (Physics Instructor)), and their research associates. Please note that, though it is unlikely, you may have Silvia d'Apollonia or Peggy Simpson as teachers in future classes. We also are requesting permission to access the results of your Dawson College English Placement Test, college grades and other assessment measures collected by the same named researchers. You will not be required to purchase anything, as all materials and software will be supplied. Lastly, if you agree to participate in this study your name will be entered into a raffle for one of three $50 prizes. Drawing of the raffle held at the end of the project, but no later than the first week of December, 2006.

ALL INFORMATION COLLECTED FOR THE PURPOSE OF THIS RESEARCH WILL BE KEPT STRICTLY CONFIDENTIAL. NO NAMES OR ANY OTHER IDENTIFICATION WILL BE USED IN ANY PUBLICATION(S) THAT MAY RESULT OUT OF THIS STUDY AND, NO NAMED DATA WILL BE RELEASED TO ANY DAWSON FACULTY. DATA WILL BE USED FOR THIS STUDY ONLY AND DISTROYED WHEN THE STUDY IS COMPLETED.

Your cooperation is voluntary. You have the right to decline participation in any part(s) of this pilot study. Also, you have the right to discontinue your cooperation at any time. Your non-participation or withdrawal will in no way affect your standing in any course(s) or program(s). Please indicate your wish to participate by filling in the appropriate section below. If you DO NOT wish to participate DO NOT return the form.

Any questions you have with respect to this research should be addressed to the principal researcher:
Elizabeth S. Charles: echarles@place.dawsoncollege.qc.ca 931-8731, ext. 1560. Any other concerns related to the conduct of the researchers should be directed to Geoff Kloos, gkloos@dawsoncollege.qc.ca 931-8731, ext. 1376.

If you sign below, it means that you have read the information on this sheet and *you are willing* to be in the study.

I agree to participate in this research project conducted by the above named individuals. I have carefully read the above description and understand the agreement. I freely consent and agree to participate in the collection of data for this research project.

Name (please print) ____

Student ID ______________________________

Student's signature _________________________________ Date ________________

Parent's signature if you are a minor (i.e., 17yrs and under) _________________________________

I would like a copy of the study's findings when they are available. __ yes __ no

If yes, please provide the researchers with your email or postal address (below). It will be sent to you at the completion of the study.

E-mail address (or postal address):

Appendix A.2

Email to recruits

Hi, I'm following up on your interest to participate in the *Promoting Conceptual Change in Physics Using Models* research project, which was introduced by the researcher, Dr. Charles, who visited your Physics class earlier this week.

This email/letter is to invite you to an information meeting, with pizza and snacks, which will be held next week. The intention of the meeting is to give you the opportunity to learn more about the project and to form the groups who will work together as teams on this research project.

The meeting is planned for after classes (starting at 6:00PM, lasting approximately 50 minutes).

The meeting will be on one of these days:
Tuesday, September 5; or Wednesday, September 6; or Thursday. September 7.

Please respond to this email immediately with the day of the week, mentioned above, works best for your schedule. If, you will not be able to attend, but are still interested in participating, please let us know when you will be available next week.

We are delighted that you have shown an interest in our project and look forward to working with you.

Thank you,

Elizabeth Charles, Ph.D.
Center of Research on Learning and Instruction in Science

Appendix B

Appendix B

SIMCAR DVD

Appendix C

TEAM 4 WORK BOOK

COASTER CAR RAW DATA COLLECTION

Form #2: Guide for Data Collection - Session 1

Variable tested:	Trials	General Observations	DATA COLLECTED: Distance (on floor) in (cm)	Time (on flat) in (s)	Avg. Speed in (cm/s)	Avg. Acceleration in (c
Value of variable tested:	1	Inaccurate	100.1	1.59	62.9	-1.7
	2	Inaccurate	127.0	1.99	63.8	-1.4
	3		521.9	9.73	53.6	-0.33
	4		609.6	9.96	61.2	-0.29
	5		632.2	10.14	62.3	-0.28
		AVERAGE	587.9	9.9	59.1	-0.30
Value of variable tested:	1		537.5	9.94	54.1	-0.32
	2		567.1	8.74	64.9	-0.31
	3		588.0	9.19	63.9	-0.30
	4		466.1	7.84	59.9	-0.37
	5		465.1	8.45	55.0	-0.37
		AVERAGE	524.8	8.8	59.5	-0.34
Value of variable tested:	1		255.5	4.32	59.1	-0.68
	2		262.9	4.57	57.5	-0.66
	3		240.0	3.79	63.3	-0.73
	4		264.2	4.24	62.3	-0.66
	5		269.2	4.40	61.2	-0.65
		AVERAGE	258.4	4.30	60.7	-0.68

The data which are marked inaccurate are not used to find the averages.

HYPOTHESES AND EXPLANATION OF RESULTS

Coaster Car			
1	The thickness of the wooden wheels Sizes: Small, Medium, Large		
2	As the wheels get thicker the friction will increases, because the mass of the wheels are getting larger. Therefore it is expected that the car with the ticker wheels slow down faster than the ones with thinner wheels?		
3	Mass of the cars The nonlinear trajectory that they may have because of the position of the axels The flatness if the track		
4	Small (Least thick) wooden wheel	Medium (Average thick) wooden wheel	Large (Most thick) wooden wheel
5	$587.9\,cm$	$524.8\,cm$	$258.4\,cm$
Average	$9.9\,s$	$8.8\,s$	$4.3\,s$
	$59.1\,cm/s$	$59.5\,cm/s$	$60.7\,cm/s$
	$-0.3\,m/s^2$	$-0.34\,m/s^2$	$-0.68\,m/s^2$
6	After leaving the ramp it was gradually slowed down	After leaving the ramp it was gradually slowed down	After leaving the ramp it was gradually slowed down
7	As the wheels get thicker the friction will increases, because the mass of the wheels are getting larger. Therefore the car slows down faster with ticker wheels. (Note that at the same time that mass of the wheels increases and that's the reason why the friction increases.)		
8	The formula for static friction is $F_s = \mu_s \times F_N$. When the object is on the flat surface the value of F_N is equal to the weight of the object F_g. So as we see when the thickness of the wheels increases, automatically their masses increase to. As the result we need more energy to move the car in the longer distance. So if the wheels are thinner and lighter we can go a farther distance with less amount of energy.		

In order to use the least amount of energy and have the longer distance traveled; we better have wheels which are light. The Newton's Second Law of motion is $\sum F_{net} = m \times \vec{a}$ and it says that for acceleration a mass we need force and as we can see for the same amount of force an object with lighter wheels will accelerate more than heavy wheels.

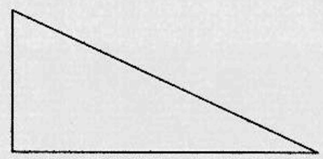
It is very important to know that if the mass of the cars were constant the thickness of the wheels wouldn't affect the result, but unfortunately keeping the mass of the car constant was not possible

Calculations

$$\text{Avg. Speed in (cm/s)} = \frac{\text{Distance (on floor) in (cm)}}{\text{Time (on flat) in (s)}}$$

mgh

17.78 cm
Or
0.1778m



$\frac{1}{2} m v_i^2$

$$mgh = \frac{1}{2} m v_i^2$$

$$gh = \frac{1}{2} v_i^2$$

$$2gh = v_i^2$$

$$2 \times 9.8 \, m/s^2 \times 0.1778 m = v_i^2$$

$$v_i^2 = 3.5 \, m^2/s^2$$

$$v_i = \sqrt{3.5 \, m^2/s^2}$$

$$v_i = 1.87 \, m/s$$

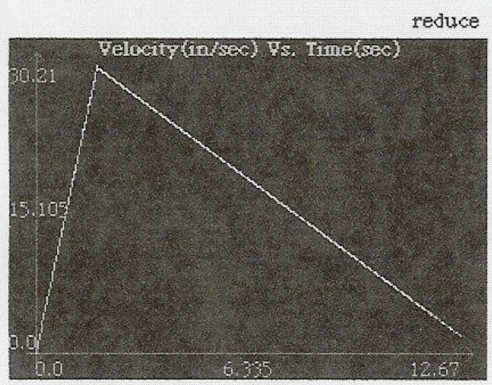
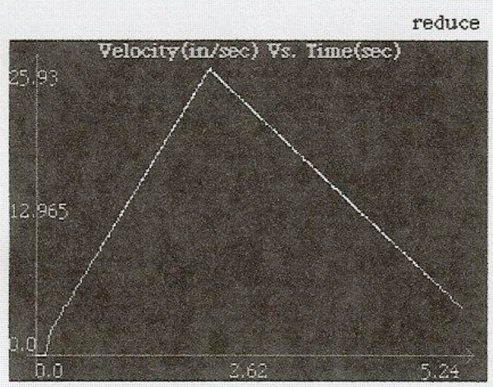
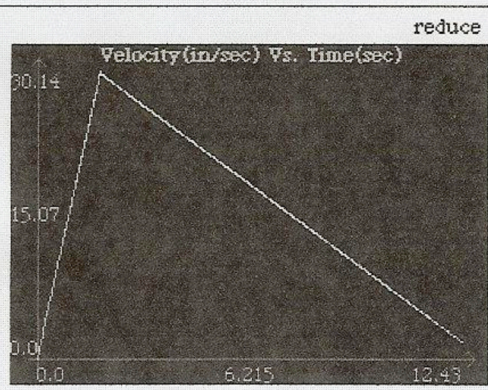
For all cars: $v_i = 1.87 \, m/s$ *and* $v_f = 0 \, m/s$

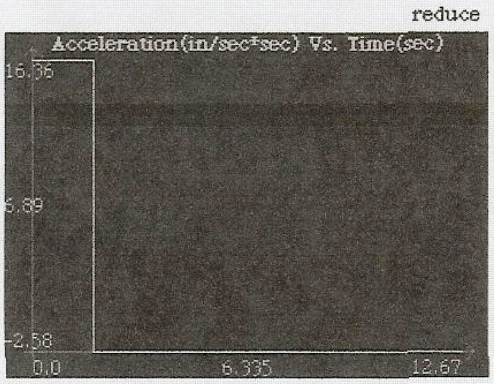
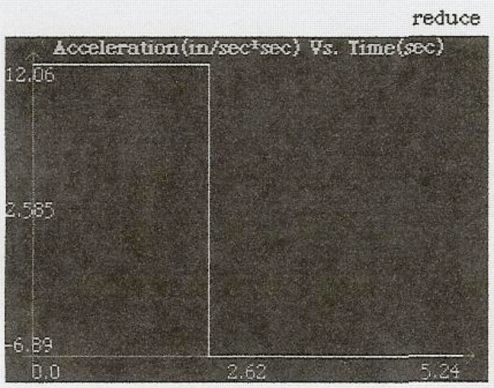
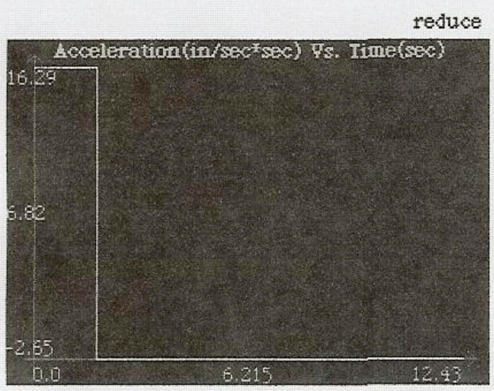
$$(v_f)^2 = (v_i)^2 + 2\vec{a}\Delta d$$

$$\vec{a} = (v_f)^2 / 2\Delta d$$

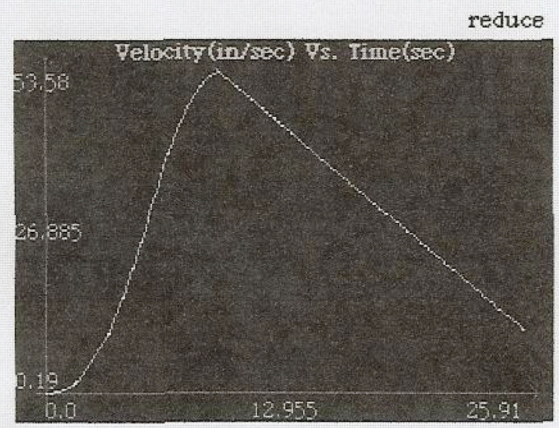
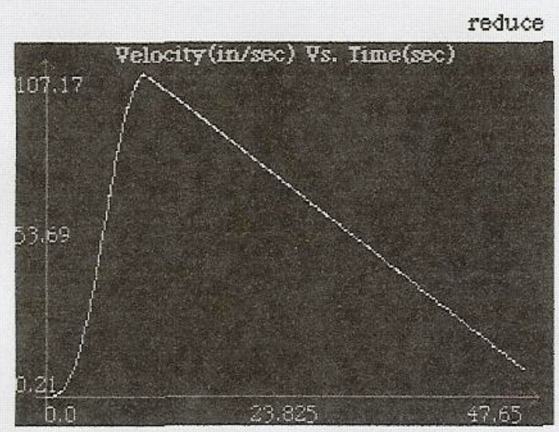
$$\text{Avg. Acceleration in } (m/s^2) = \vec{a}$$

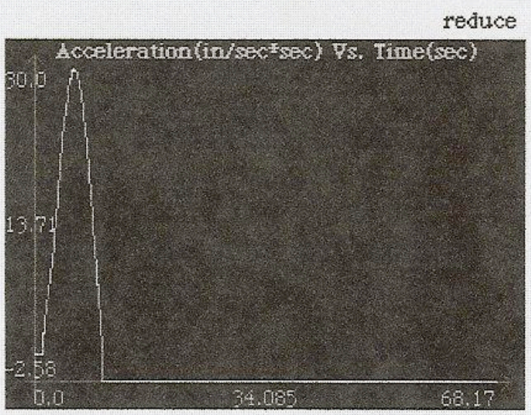
SIMCAR – COASTER CAR SIMULATION OUTPUTS AND EXPLANATIONS

<table>
<tr><td colspan="3">Coaster Car</td></tr>
<tr><td>1</td><td colspan="2">The material of the wheels
Types of the wheels: CD, Wooden, Gear</td></tr>
<tr><td>2</td><td colspan="2">The velocity will increase at a positive rate at the beginning and after a while it will decreases in a negative rate and after all it will be zero.</td></tr>
<tr><td>3</td><td colspan="2">The acceleration is constant and positive at the beginning and after a while it will be constant and negative and after all it will be zero.</td></tr>
<tr><td>4</td><td>
</td><td>CD Wheels</td></tr>
<tr><td></td><td>
</td><td>Wooden Wheels</td></tr>
<tr><td></td><td>
</td><td>Gear Wheels</td></tr>
</table>

5		CD Wheels
		Wooden Wheels
		Gear Wheels
6	At the beginning a constant positive force was applied to the car. This force was in the direction of the motion of the car. It was responsible for over coming the friction. That's the reason why we see the velocity is constantly increasing. After a while the force of friction over come our moving force makes the car to decrease its velocity in a constant and negative way.	
7	At the beginning a constant positive force was applied to the car. This force was in the direction of the motion of the car. It was responsible for over coming the	

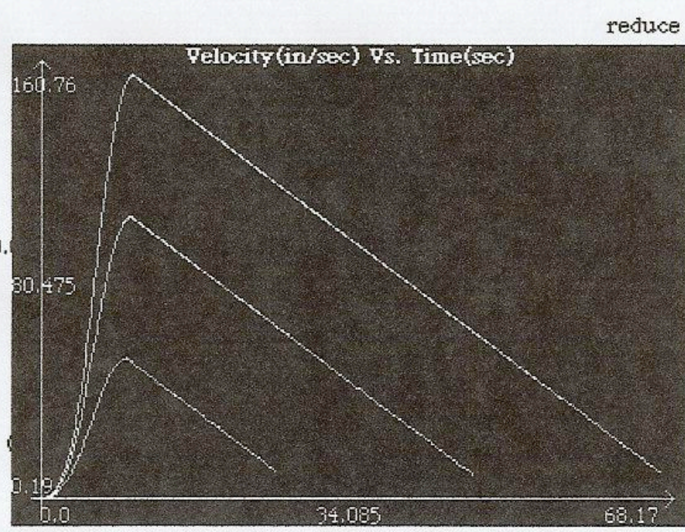
SIMCAR - BALLOON CAR SIMULATION OUTPUT AND EXPLANATIONS

	decreases in a negative rate and after all it will be zero.	
3	The acceleration is positive but not constant at the beginning and after a while it will be negative and again not constant. At the end it will be zero.	
4		1 Balloon
		2 Balloon

		3 Balloon
6	At the beginning an increasing, positive and non constant force was applied to the car. This force was in the direction of the motion of the car. It was responsible for over coming the friction. That's the reason why we see the velocity is increasing. After a while the force of friction overcomes our moving force and makes the car to decrease its velocity in a no constant and negative rate.	
7	At the beginning an increasing, positive and non constant force was applied to the car. This force was in the direction of the motion of the car. It was responsible for over coming the friction. That's the reason why we see a positive and non constant acceleration. After a while the force of friction overcomes our moving force and makes the car to slow down and have a non constant negative acceleration.	

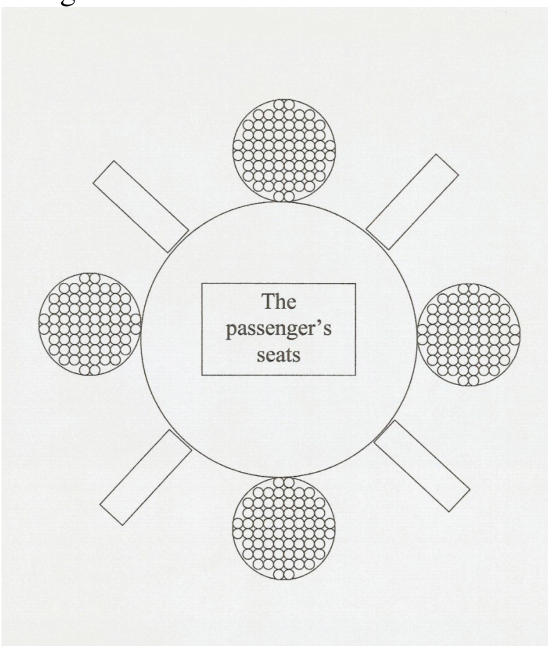
The decreasing order of the maximum distance traveled, time, velocity and acceleration would be be: 3 balloon car, 2 balloon car, 1 balloon car

Comparison of the Graphs



FINAL DESIGN CHALLENGE

Design for Antarctic Vehicle



Explanation

This car is based on the Newton's First Law of motion. This law says once an object is put in motion it will continue in the direction of motion with a constant velocity. The inertia is the responsible for this phenomenon. The problem on the surface of the earth is the friction which stops the moving object. So we decided to get rid of this friction. The four medium circles are full with very small ball bearings. At the same time a pressured air goes between these ball bearings and also between them and the surface of the earth so we would have a friction less surface. Then simply by releasing pressured air from those four rectangles we can change the direction of the car. As long as we move in a strait path we have to only release the pressure gas once to provide enough inertia for the car. Also we can put two pedals in the passenger's seat so if the passengers like to save the pressured gas and also do some exercise.

Team 4 In Class Optional Assignment Based On NYA Lab Manual

Question 1: Modifications and thoughts

This lab's purpose is to help realize the importance of building models for real world issues. Models can often be a simple cost effective way of testing how the real object might act. A good model can sometimes even predict the outcome exactly as the experimental data shows us. To achieve this, models must take into account real world apprehensions such as friction, drag and other obstacles that would change the data obtained. So models shouldn't only take into account ideal examples of a phenomenon.

To serve this purpose, we are modifying a previous lab to incorporate rolling friction. Major modifications will include:

- Expanded theory section
- Two addition questions pertaining to rolling friction and Newton's Laws in models.

We can honestly say that we learnt quite a bit about models through our participation in this project. The fact that major companies around the world rely on similar models to test out their products at a low cost, instead of making life sized functioning replica each time. While researching for the optional assignment, we came across the site of the U.S. national renewable energy laboratory, which does this exact thing. They use simulations to test for:

- Fuel economy
- Vehicle performance
- Exhaust emissions
- Vehicle component cost and market potential.

In brief, models aren't at all limited to just the classroom; on the contrary they are heavily used in industries and are an important tool.

Part I

Theory:

In this lab, through the use of the computer and a smart pulley system, we will study the motion of a cart with an applied force on a nearly frictionless track in order to prove Newton's second law.

The applied force, in this case, comes from the weights we hung on hanger attached to the cart and allowed to hang over the side of the table to allow the cart to accelerate forward.

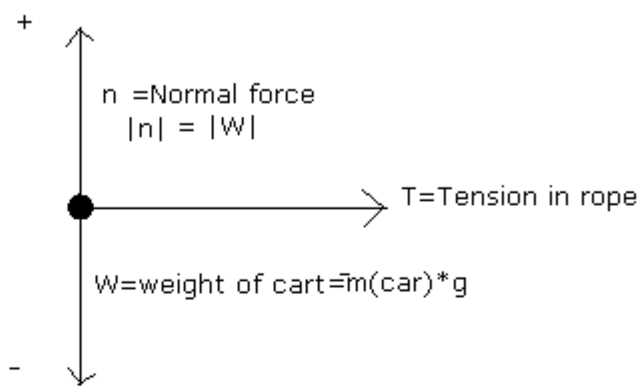
Newton's Second Law states that the acceleration of a mass is directly proportional to the net force acting on it and inversely proportional to its mass, therefore we obtain:

$$\Sigma f_{net}=ma$$

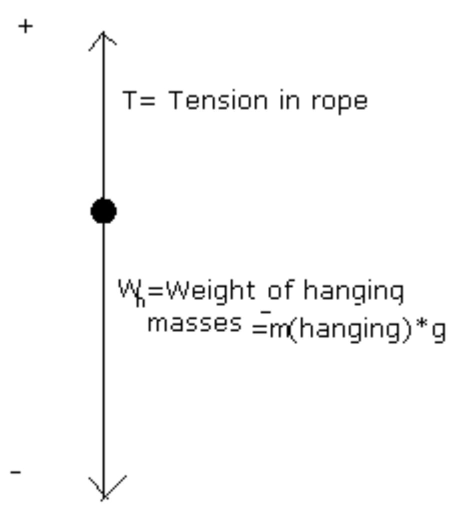
Where m is the mass, a is the acceleration of the system and Σf_{net} is the sum of all external forces.

In our experiment, we have one system with two components: the cart and the hanging mass. We should be able to apply Newton's 2nd law to the system as a whole but also to each component. We can use free body diagrams (FBD) to illustrate the forces that are acting on each component:

The cart



The hanging mass



As we can see in the first FBD, we have neglected friction. Furthermore, the normal force of the cart and its weight cancel each other out, so the net force results in the tension in the rope that pulls the cart forward. This tension arises due to the weight of the hanging mass. So in this situation $\Sigma f_{net} = T$

In the 2nd FBD, there is no normal force because there is no contact with the surface. Tension in the rope is the same in both cases, and we see that the force of the Hanging weight is greater than the ropes tension, which causes the cart to move forward and the hanging mass to accelerate downwards. The total net force in this situation would be equal to: $\Sigma f_{net} = T - W_h$.

We can use the information provided by the FBD's, if we take into account that $\Sigma f_{net} = m_{total} * a$, to say that $T = m_c * a$ and $T - W_h = -m_h * a$ (acceleration downwards) we can isolate T in both equations (same tension throughout the rope) and get the following relation between the two:

$m_c * a = -m_h * a + W_h$

$m_c * a + m_h * a = W_h$ Then we isolate the terms with a to one side and take it out as a common factor.

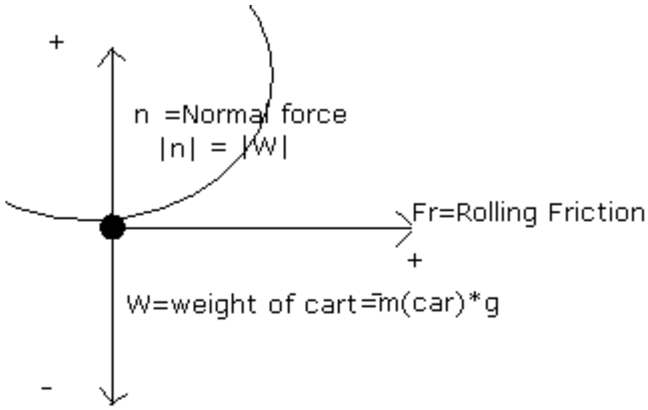
$a(m_c + m_h) = W_h$ Next we isolate a and we get the equation in the form

$a = mW_h + b$

$$a = \frac{1}{(m_c + m_h)} * W_h$$

The track on which the cart is on is virtually free of kinetic friction. Yet, there is one major force that actually allows the cart to move forward that was neglected. This force is that of rolling friction. In fact without this friction, we would observe the wheels just sliding across the track, and not necessarily revolving.

In mechanics, friction plays a major role both in the laboratory and industrial worlds. Friction is the resistance to the sliding, rolling, or flowing motion of an object due to its contact with another object. Rolling friction is caused primarily by the interference of small indentations formed as one surface rolls over another. It is much smaller than kinetic friction. This is the idea behind the frictional forces involved with wheels, cylinders, and spheres. In pure rolling motion, friction causes the wheel to catch and stops the sliding and slipping motion; for example when a car spins its tires, slipping is taking place, thus the frictional force works to stop the spinning out and causes the tires to catch and begin pure rolling motion.



The force of rolling friction can be calculated in the exact same way as other friction; however you do need the coefficient of rolling friction, which is determined by various factors such as the radius of the wheel and the type of surface in contact.

$$F_r=N*u_r$$

Questions:

1. How does Newton's 3rd law apply in these models? (Especially when taking into account rolling friction)

2. If the coefficient of rolling friction is 0.0025, what force of rolling friction is acting on the cart?

Part II

The idea of propulsion is an interesting concept when dealing with the balloon car. Firstly, the idea of propulsion is equal to the change in momentum (impulse) over a period of time. The term propulsion means to push forward or to drive an object in a specified direction. In our case, the air in the balloon is used to propel the car forward.

"The thrust equation shows that the amount of thrust generated depends on the mass flow through the engine and the exit velocity of the gas" (Benson). The thrust force can be derived by the equation: $F=[(mV)_2 - (mV)_1]/(t_2 - t_1)$ or in other words $F_{thrust}=\Delta p/\Delta t$.

In order to test for propulsion in our experiment, it is important to test for the variables in the equation in order to obtain a thrust force. The way that it could be accomplished would be to test the average velocity of many test runs (just like what we did) and calculate the average time and plug the values into the equation in order to find the thrust force of the air pushing out of the balloon making the car travel a specified distance.

Another interesting idea about propulsion is mass flow rate. This is calculated by mass/ time. The idea of mass flow rate would explain how the property of air in the balloon reacts over different amounts of time, making it possible to predict how far the car would go with an exact amount of air in the balloon. The mass of the air could be determined by using density. The mass flow rate could then be determined by plugging in acquired values. Another interesting test would be to fill the balloon with different gasses and find the different rates of thrust and propulsion for each different type of gas – that would be really interesting.

Finally, in order to test the effectiveness of exhaust velocity, in our case the air coming out of the balloon, the equation $V_e = F/m$ should be used, where V_e is the effect exhaust velocity, F is the thrust force, and m is the propellant mass flow rate. This equation can be incorporated with the different gasses in the balloon and how they should react. It would be very interesting to test the different types of gasses and see which one propels the car to travel over the furthest distance in the shortest amount of time.

This project helped with the visualization aspect of Newton's laws. It was a very interesting way of introducing the idea of free body diagrams into 'real life' and be able to create a three dimensional concept of ideas and formulas discussed in class. It is important to understand what is happening in order to fully excel and in doing this extra-assignment it helped in the understanding section of mechanics. The assignment was not life changing, however it did simplify certain ideas and create a sense of relevance to physical means learnt in class and applying them to 'real, everyday' scenarios. The project was beneficial and it was fun to build models and test their capabilities.

References

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Sep. 25th, 2006. Dec. 18th 2006. <http://www.grc.nasa.gov/WWW/K-12/airplane/bgp.html>

National Renewable Energy Laboratory: Advanced Vehicules and Fuels Reasearch
Dec. 18th 2006. < http://www.nrel.gov/vehiclesandfuels/vsa/>

Kurtus, Ron. Rolling friction
Dec. 18th 2006. < http://www.school-for-champions.com/science/frictionrolling.htm>

Appendix D

Appendix D.1

Demographic Information & Knowledge of Scientific Models Questionnaire

Student ID: __________________ Fall 2006
Program enrolled in: ______________________
Your last science/physics course was ________________

The questionnaire below is intended to help the researcher (named above) learn something about you and your understanding of models in science. Your participation and candid (open and honest) answers are greatly appreciated.

CIRCLE THE LETTER RELATING TO YOUR ANSWER & FILL IN WHERE APPORPIRATE.

1. I read science magazines:
   (a) often, (b) sometimes, (c) never.

   If (a) or (b), what are some of your favorite subjects to read about?
   ____
   ____

2. I watch or listen to science programs on television or radio:
   (a) often, (b) sometimes, (c) never.

   If (a) or (b), what are some of your favorite subjects to read about?
   ____
   ____

3. Do you play games, simulations, etc., that might be considered science related, or help you better understand science?
   a. Yes
   b. No

   If yes, in which way(s) do you think these might be related to science or help you better understand science?
   ____
   ____

4. I belong (have belonged) to a science club:
   (a) currently, (b) years ago, (c) never.

5. I've entered science fair competitions:
   (a) several times, (b) once, (c) never.

   If you answered (a) or (b), what was your project?

____
____

What did you learn? (e.g., learned to design experiments, collect data, analyze, write reports)
____
____

Did your project win any awards (you may elaborate if you wish)?
____
____

Was your project a team project?

a. Yes
b. No

If yes to the above, what was your experience with this type of team/group learning?
____
____

The following questions are intended to assess your understanding of scientific models and find out about your views on how they relate to your understanding of science. Please answer them using complete sentences, i.e., with details and/or examples. Where appropriate, check off which statements are appropriate.

6. How would you explain what is meant by a ***scientific model.*** Be sure to include what is the purpose of such models and give examples.
____
____
____
____
____
____

7. Have you ever used models/simulations/computer programs to learn science/physics (e.g., Lego; chemistry models; java applets teaching physics; StarLogo)? Describe these experiences.
____
____
____
____

Appendix D.2

Epistemic Beliefs of Models Questionnaire

Using a scale of 1- 5, indicate your thoughts on the following by filling in the circle beside the number: (1= strongly disagree, 2= disagree, 3= no opinion, 4= agree, 5= strongly agree)

Models are used to:	
• Show an idea	1○ 2○ 3○ 4○ 5○
• Explain scientific phenomena	1○ 2○ 3○ 4○ 5○
• Physically or visually represent something	1○ 2○ 3○ 4○ 5○
• Show a smaller scale size of something	1○ 2○ 3○ 4○ 5○
• Show the relationship of ideas clearly	1○ 2○ 3○ 4○ 5○
• Make and test predictions about a scientific event	1○ 2○ 3○ 4○ 5○
• Help formulate ideas and theories about scientific events	1○ 2○ 3○ 4○ 5○
• Show how they are used in scientific investigations	1○ 2○ 3○ 4○ 5○
• Help create a picture in your mind of the scientific happenings	1○ 2○ 3○ 4○ 5○
A model may be changed if:	
• There are changes in data or beliefs	1○ 2○ 3○ 4○ 5○
• There are new findings	1○ 2○ 3○ 4○ 5○
• New theories or evidence prove otherwise	1○ 2○ 3○ 4○ 5○
A model needs to be close to the real thing by:	
• Being very exact, so nobody can disprove it	1○ 2○ 3○ 4○ 5○
• Being very exact in every way except for size	1○ 2○ 3○ 4○ 5○
• Being as close as it can be to the real thing	1○ 2○ 3○ 4○ 5○
• Giving the correct information and showing what the object/thing looks like	1○ 2○ 3○ 4○ 5○
The features if a model are as follows:	
• It should be an exact replica	1○ 2○ 3○ 4○ 5○
• Everything about it should be able to tell what it represents	1○ 2○ 3○ 4○ 5○
• It shows what the real thing does and what it looks like	1○ 2○ 3○ 4○ 5○
• Has what is needed to show or explain a scientific phenomenon	1○ 2○ 3○ 4○ 5○
• It can be a diagram or a picture, a map, graph or a photo	1○ 2○ 3○ 4○ 5○
Many models may be used to express features of a science phenomenon by showing:	
• Different versions of the phenomenon	1○ 2○ 3○ 4○ 5○
• Different sides or shapes of an object	1○ 2○ 3○ 4○ 5○
• Different parts of an object or showing the object differently	1○ 2○ 3○ 4○ 5○
• Different perspectives to view an object	1○ 2○ 3○ 4○ 5○
• How different information is used	1○ 2○ 3○ 4○ 5○
• How it depends on individuals different ideas on what things look like or how they work	1○ 2○ 3○ 4○ 5○

Appendix E

Appendix E
Post-Intervention Interview Questions

NAME: ___________________________
DATE & TIME: _____________________
INTERVIEWER: ____________________

NOTE TO INTERVIEWER: The following questions are intended to assess the student's understanding of scientific physics models and find out about your views on how they relate to their understanding of physics.

AS FULLY AS POSSIBLE EXPLAIN TO ME THE FOLLOWING, GIVIGN EXAMPLES WHERE APPROPRIATE

1. How would you **NOW** explain what is meant by a ***scientific model.***
    - What is the purpose of such models ?
    - Can you give examples?

2. How did the experience (working with cars & the computer model SIMCARS) help you build your understanding of mechanics?

3. To what degree has this experience (working with cars & the computer model SIMCARS) helped you understand scientific reasoning (i.e., experimentation)?

4. Briefly describe what were the most important things, if any, you learned from this experience?

5. How do you think it helps you, if it did, with your physics course (NYA or DSP)?

6. What suggestions do you have, if any, that would improve the experience?
    The list of activities:
    - building cars.
    - playing with the computer model.
    - pre-instruction activity (intro session).
    - post-instruction wrap up activity of building a car for the Antarctic.
    - Working in groups.

Appendix F

Appendix F.1
FCI pretest

Appendix F.2
FCI Posttest

Appendix F.3
FCI Answer Key

FCI Answer Key

FCI-All Question	FCI-All Answer	FCI-Pre-test Question	FCI-Pre-test Answer	FCI Post-test Question	FCI Post-test Answer	Concept
1	C	1	C			Forces
2	A	2	A			Forces
3	C			2	C	Forces
4	E	3	E			Third Law
5	B	4	B			First Law
6	B			3	B	First Law
7	B	5	B			First Law
8	B	6	B			First Law
9	E			5	E	Kinematics/Second Law
10	A	7	A	6	A	First Law
11	D	8	D	7	D	Gravitation/Forces/Third Law
12	B	9	B			Forces
13	D	10	D	4	D	Forces
14	D			8	D	Kinematics
15	A	11	A			Third Law
16	A	12	A	9	A	Third Law
17	B			1	B	First Law/Superposition
18	B			10	B	?
19	E	13	E	11	E	Kinematics
20	D	14	D	12	D	Kinematics
21	E			14	E	Kinematics/Second Law
22	B	15	B	15	B	Kinematics/Second Law
23	B	16	B			First Law
24	A					First Law
25	C	17	C	17	C	First Law
26	E	18	E	18	E	First Law
27	C	19	C	19	C	Forces
28	E			20	E	Third Law
29	B	20	B			Forces
30	C			13	C	Forces

Appendix G

Formal Reasoning Questionnaire

Appendix H

Document Literacy Questionnaire

Appendix I

Team 3 Session 4			
Time	Context	Description	Note
00:00-00:20	classroom, 2-way group work, talking physics	traction between wheel and floor	UOS
00:21-02:50	classroom, 3-way group work, building	building car with 3 balloon engines, blowing up balloons	
02:51-04:50	classroom, 3-way group work, debugging	first balloon not deflating, test defective balloon, reject it and use new balloon engine for replacement after testing it first	DOE
04:51-05:50	classroom, 3-way group work, building	blowing up balloons	
05:51-06:30	classroom, 3-way group work, testing	test 3-balloon engine design; Ray "do you think it's going straight enough?", Floyd "it's ... the distance we travel ... a little minor deflection and ..."	UOD
06:31-06:47	classroom, 3-way group work, discussion, talking science	Gilles "if we can predict which way it's going to turn, we just enter it into the calculations", "we can do it on the left so it goes to the right ... it assumes a triangle, so it's easier"; Ray "do you want to ... try it now?"	HLT
06:48-11:12	classroom, 3-way group work, building	blowing up balloons; ask for and get a new balloon pump	DOA
11:13-11:17	classroom, 3-way group work	preparing to test, getting materials	
11:18-12:50	hallway, 3-way group work, trial	planning before running trial, measure out predicted distance car will travel, carefully line up car	DOE
12:51-12:54	hallway, 3-way group work, trial	run trial, "it's not going straight", "at least we know in which direction it's turning"	UOD
12:55-14:11	hallway, 3-way group work	measuring distance, recording distance and time	
14:12-14:30	hallway, 3-way group work	discussion, too quiet to hear, camera moves toward group	
14:31-14:37	hallway, intervention	Researcher 1: talking to Gilles, Gilles goes off-camera	
14:38-14:58	hallway, 2-way group work, debugging	trying to determine why car not going straight; Floyd "do you want to re-weigh it? ... but it's only a couple of grams..."	DOE

14:59-15:22	hallway, 3-way group work	Gilles back; Ray "do you want to just try it again?"; decide to run next trial	
15:23-15:53	hallway, 3-way group work	preparing for trial, get pump	
15:54-16:10	hallway, 3-way group work	debugging, prediction, Gilles "it's going this direction, so maybe if we turn it that way"	DOE, HLT
16:11-17:00	hallway, 3-way group work	preparing for trial, blowing balloon	
17:01-17:11	hallway, 3-way group work	debugging, Gilles "there was something wrong with the last one ... maybe we didn't release it all at once"	HLT
17:12-18:36	hallway, 3-way group work	preparing before trial, planning on direction to launch	
18:37-20:46	hallway, 3-way group work, trial	running trial; Gilles "it's wobbling"; recording distance and time; can't hear conversation then talking about other group's trial	UOD
20:47-20:52	hallway, 3-way group work	talking about how many trials to do, Floyd "the results are still different"	DOE
20:53-21:06	hallway, intervention	Researcher 1: suggests doing another trial to deal with different results	
21:07-21:12	hallway, 3-way group work	Floyd comments on changing axles after first trial	DOA
21:13-24:21	hallway, 3-way group work	preparing for trial, blowing up balloons	
24:22-24:57	hallway, 3-way group work, trial	running trial	
24:58-25:18	hallway, 3-way group work	recording distance; Floyd "that's 3 feet longer than the last longest one"	UOD
25:19-26:00	hallway, intervention	Floyd telling Researcher 1: about differences between trials, Researcher 1: asks if group seeing a trend, Floyd "they keep getting longer", Researcher 1: "that's something you need to explain"	UOD
26:01-26:17	hallway	distracted by other group's trial	
26:18-26:20	hallway, intervention	Researcher 1: "try to explain that"	
26:21-26:43	hallway, 2-way group work	Gilles and Ray talking about wheel looseness	DOA
26:44-29:44	hallway, 3-way group work	preparing for trial, blowing balloons; distracted a bit by other group; align car before launch	
29:45-30:32	hallway, 3-way group work, trial	"it's going really straight"; recording distance and time	UOD
30:33-30:42	hallway,	Researcher 1: "that's a little closer to the	

	intervention	last one"; Floyd "yeah, it's more closer to the mean"	
30:43-30:57	hallway	distracted by other group	
30:58-31:11	hallway, 3-way group work	talking about how many trials to do, move to classroom	DOE
31:12-32:15	classroom, 3-way group work	weighing car; Gilles "the wheels were very straight this time, there was no wobbling", Ray "but it didn't go as far"	UOD
32:16-33:00	classroom, intervention	Researcher 1: suggests group starts talking about differences before adding more engines	
33:01-33:49	classroom, 3-way group work	decide to do 1, 2, and 3 balloon engines, remove 2nd balloon	DOE
33:50-33:59	classroom, 3-way group work	prediction Floyd "it's not going to go as far"	HLT
34:00-34:59	classroom, 3-way group work	weighing car	
35:00-36:29	hallway, 2-way group work, trial	Floyd & Gilles preparing car for trial	
36:30-36:57	hallway, 3-way group work	prediction, Gilles "do you think it's going to go left this time? ... we moved one of the straws, maybe it will go in a different direction?"	EXB
36:58-37:58	hallway	waiting to run trial	
37:59-39:11	hallway, 3-way group work, trial	run trial, record distance and time, Floyd "it's going farther"	UOD
39:12-40:07	hallway, 3-way group work, talking science	prediction, Ray "then we know we've reached our peak, if we added more, it would go less, you know, benefits vs. ..." Floyd air-drawing on wall, Ray "I don't know if it's a parabola" ... talking about pattern of distance being affected by balloon engines	EXF, HLT
40:08-41:57	hallway, 3-way group work, trial	preparing trial; running trial	
41:58-43:19	hallway, 3-way group work, trial	Ray "it's pretty constant"; recording distance and time	UOD
43:20-46:46	hallway, 3-way group work, trial	preparing trial, blowing car, aligning car, waiting for other group, running trial	
46:47-47:32	hallway, 3-way group work, trial	recording distance and time; Ray "it's pretty consistent", Floyd "it's like we create more consistency when add more balloons"	UOD, HLT
47:33-	hallway, intervention	Researcher 1: tells group to come in classroom	
47:53-49:17	classroom, 3-way	Floyd "on average it went further with 2	UOD, HLT

	group work, talking science	balloons than 3 balloons in approximately the same time ... I'm not calculating ... there's no use adding more balloons", Ray "it was pretty consistent"	
49:18-59:10	classroom, 3-way group work, motion storyboard, talking science	drawing motion storyboards, figuring out how to draw them as they're doing it; Researcher 1: talking at same time but group works while she's talking; talking physics while figuring how to draw	UOS
59:11-59:37	classroom, 3-way group work, talking science, other presentations	Researcher 1: lecturing, getting Team 4 to present; group still talking science	UOS
59:38-1:00:00	classroom, 2-way group work, talking science	Team 4 presenting; Floyd listening to them; Ray and Gilles working quietly, talking science	UOS
1:00:01-1:07:25	classroom, other presentations	Team 4 presenting; group listening	
1:07:26-1:08:13	classroom, other presentations	Team 4 presenting; group listening; Frank trying to answer Researcher 3's question about forces acting in-between balloon going limp and car stopping, Ray "but there isn't a force for propulsion" "as soon as it's limp it slows down because it's losing its propulsion" "it no longer has propulsion so it decreases"	UOS, HLT
1:08:14-1:09:27	classroom	Team 4 presenting; group listening	
1:09:28-	classroom, group presentation	Team 3 presenting; "we found there was a peak ... you could add more balloons and it wouldn't go faster ... because of increased drag, increased resistance... it's the same slope of the line so you'd end up in the same place"	UOS
1:11:10-1:14:48	classroom, other presentations	Team 2 presenting; group listening	
1:14:49-1:18:34	classroom, other presentations	Team 2 presenting; in response to 'last gasp' phenomenon; Floyd "it's PK and RT, there's a huge pressure", Ray "there's a huge pressure"; Floyd "[pressure and volume] inversely proportional"; Floyd "maybe it's a property of the balloon, of the latex", Ray "it's the stretch"	UOS, HLT
1:18:35-1:19:14	classroom, Researcher 1: lecturing	in response to Researcher 1:'s question about elasticity; Floyd "there could be differences between the balloons	HLT

		themselves, it's better to keep the same balloon, you're just reducing... you're just going to stretch the time"	
1:19:15-1:24:00	classroom, Researcher 1: lecturing	group listening	
1:24:01-1:25:35 (end)	hall, Researcher 1: filming balloon car	Researcher 1: and Researcher 3 filming balloon car	

Team 3 Session 4

Transcript of storyboard episode discussing force vectors

Episode 1

48:34

Researcher 1: if you guys can take a look at the motion storyboard.

Floyd: (directed at Gilles) since you're so smart, you're in charge.

Gilles: (laugh) ok, let me at it.

(three boys working on the same side of the table – Ray (face obstructed by the tower of the car), Gilles (in the middle and standing), and Floyd with the storyboard paper directly in front of him.

49:09

Gilles: alright, so, it's hard reading upside down.
Ray: (laughs) ha, ha, ha.
Floyd: so we're doing a picture of the balloon?
Gilles: yeah.
Floyd: I'm not the artist, Gilles the artist (handing over the pen to Gilles). You can have the chair too. (gets up and gives Gilles the seat).
Gilles: uh, really (laughs). I already drew, you know.
Floyd: yeah, it's genius (points to the paper).
Gilles: no it's not.
Floyd: It's like Picasso.
Gilles: Picasso, (laughs) exactly.
Gilles: besides that it works pretty well.
(both are bent over the paper and pointing at the drawings and cells on the motion storyboard)
Floyd: so speeding up it's going to be slight ...
Gilles: (same time) just slightly smaller.
Floyd: slightly smaller. (points) And slowing down it's going to be slightly smaller. I don't get the point of this (points). For the balloons it really doesn't matter.
Gilles: yeah (laughs), I'm pretty much guessing it. So you know it's... OK anyway, we can do this at home.
Floyd: OK (same time as Gilles). Yeah, why don't we, we skip that one (points to next line). OK, dots!
Gilles: dots! (same time as Floyd).
Floyd: OK, so at the start it's speeding up so the distance between the dots is getting bigger (points).
Ray: yeah.
Gilles: oh! You mean just draw dots.
Floyd: yeah, you have to draw a dot diagram. (draws). Like this.
Gilles: yeah, yeah, yeah, I just get it. It's speeding up so let's say this, then ... (drawing)
Floyd: bit further, (gestures a waving in direction of the movement).
Gilles: further, and. Oh! Yeah, you're right! (erases). You have to.

Floyd: it’s speeding up, it’s speeding up (moves to an upright position).
Gilles: mais (but), it’s just like.
Floyd: No, it’s going the other way (points to the left and then returns to the bent over position). (laughs).
Gilles: it’s not so bad.
Floyd: just make it very visual. You don’t have to be specific, (corrects himself) precise. (standing up and is playing with the balloon pump).
Gilles: yeahhh. (momentary silence 2 sec while Gilles draws). It’s actually (got to be (inaudible) look?). (stands upright looking at the drawing). Yeahhh (gestures).
Floyd: OK, yeah. (uses pump to point to the cell on the storyboard).
Gilles: I’m sure at start it’s not moving. (points) That one’s speeding up.
Floyd: oh.
Gilles: (scratches his head) ok, (bends over again and starts drawing) so let’s just consider we move this here (stands upright and gestures)
Floyd: ha, ha (laughs)
Gilles: see. (bends back down and returns to drawing) But what it starts then? What is start, if it doesn’t move at start? (stands upright and directs the question to Floyd).
Floyd: (pointing to drawing) so is that the start? But time is zero (overlapping).
Gilles: (same time) time is zero
Floyd: time is zero (pointing), means there’s no movement (shaking his hand while pointing) so (it means it’s not gone?).
Gilles: no movement (shoulder shrug), alright. (bends back down and goes back to the drawing) it’s like, you would have like five dots or six points all at the same point. So you have (erases), you just don’t (?) (laugh). (stands back up). OK, and slowing down is the exact opposite.
Floyd: you’re also (slowing down?)
Gilles: do I write the sign minus one? No?
Floyd: (bends over to draw) no, just write it.
Gilles: well go for it (pushing the paper over to Floyd)
50:54
Floyd: (drawing 10 sec).
Gilles: yeah, that wasn’t very...
Floyd: (and erasing some of the drawing)
Gilles: um. So what is this? Force... force acting on it?
Floyd: that’s the force. (?)You can start doing that. The (?) it’s going to be the same
Gilles: (turns to Ray) do you want to some of this?
Ray: (motions, go ahead)
Gilles: (bends back down to work). well Ok, um, well I can’t , there’s (stops because of the interruption)

51:21
T: can everyone ....

Episode 2
52:04

Gilles: ok, forces at the end, there's no forces except gravity.
Ray: No, (pointing to the cell on storyboard) forces, the natural force, the weight. The natural force goes up, (gestures with a thumb up) goes up.
Gilles: yeah.
Ray: and slowing down, there's the same natural force, weight, um, slowing down...
Gilles: (turning to Ray) plus friction is bigger than at the beginning.
Floyd: (returns his attention to the group)
Ray: no...
Gilles: so we have here, a little acceleration from the balloons
Ray: yeah, (pointing) and a lot greater (friction?)
Floyd: yeah, we have velocity that way, acceleration that way (pointing forward), and friction backwards (point backward).
Ray: (nods).
Gilles: and friction. But here friction is big than the balloons, and here it's opposite. Here balloons, is, bigger, than friction (said slowly as he draws it out then stands up).
Floyd: yeah, and you have the "g" and "b".
Ray: don't forget (pointing) you have the gravity and the natural force.
Floyd: isn't it normal?
Ray: yeah, normal, sorry.
Gilles: actually, "b" at the beginning should be the biggest. At the start the "b" force is longest (gestures).
Floyd: no, time is zero, so nothing's happening yet.
Gilles: well, it's the moment between just leaving (gestures a release motion), I think, time zero.
Ray: (overlapping) oh yeah, well consider that a (?) force (gestures a pump of the fist).
Gilles: just like a force is there but not, yet, movement. Like the very beginning of acceleration.
Floyd: oh, yeah, So there's a huge one (drawing).
Gilles: very huge one.
Ray: and the, and the um...
Floyd: (talking over) oh, there's static friction stopping it from moving (turns to Gilles).
Gilles: yep (nods).
Ray: (nods) ah um. also, don't forget the static friction.
Gilles: so let's say it is (drawing)
Floyd: so it's equal.
Ray: ummm.
Floyd: (gesturing) if it's not moving then the static force, the balloons haven't overtaken it yet.
Gilles: yeah.
Ray: yes that's true because we're not talking about in motion at that time (pointing to the storyboard).
Floyd: so it should be exactly equal.
Ray: yeah.
Floyd: and then this one, when it stops is at kinetic friction
Ray: (overlapping) static and kinetic.

Gilles: yeah, but there's no acceleration from the balloons, so there's no. Well, there's static friction (gesturing). But there's, it's going to be in equilibrium. And it's not moving. So...
Floyd: it's hard to think about.
Gilles: it's hard to think about yeah, but. Yeah, there is friction force but it's...
Floyd: the balloon's conked out (points to storyboard), so then there's no friction, because it's not moving.
Ray: no, no
Gilles: (looks quizzical).
Floyd: (stand up and counts out the factors with his fingers), there's nothing from the balloon, it's not moving forward.
Ray: (talking over) there's no kinetic friction but there is static friction because it's at rest.
Gilles: yeah,
Floyd: yes. (same time)
Gilles: but, (whereas ?) if we put kinetic friction there, I would be telling that this is...
Floyd: (talking over) If you, (gesturing toward storyboard) yeah, yeah, something has to be pushing forward.
Gilles: yeah, and nothing is pushing forward then.
Floyd: (talking over) you can't have, you can't have unbalanced, uh, frictional force.
Gilles: yeah, cause it would mess it up
Floyd: (gesturing) you can't have a frictional force without something...
Gilles: counterb.., qui, this thing is not moving (turning to look at Ray).
Ray: (looking at Floyd) yeah you can.
Floyd: you can't have a force pulling back on something (gesturing).
Ray: it's not pulling back on it, it's just, it's just maintaining it there.
Gilles: then which direction is it?
Ray: remember when we're learning it (??)
Floyd: but static friction works both way (gesture back and forth).
Ray: yeah, ok, fine.
Floyd: well, which way is it going?
Gilles: so where is it?
Ray: well fine, you could, you could neglect it but...
Floyd: because, look, (touches the car), when it's sitting there's static friction but it's the same that way, same that way, same that way, same that way (pointing out the 4 directions).
Gilles: same that way, same that way (pointing up and down).
Ray: (talking at same time) yeah, yeah.
Floyd: So there's nothing at all.
Ray: ok (with resignation).
Gilles: so, yeah, it's like, it's just sitting there.
End of episode
54:37

Episode 3

54:39

Floyd: ok, so Fnet, here there, it's zero. It's not moving at all.

Gilles: no it is. At the very beginning the force net is "b," a small balloon force.

Floyd: The "T" is zero, it's zero.

Ray: it's zero.

Gilles: but there's already a force acting (pointing to storyboard).

Floyd: but we said that they're equal.

Gilles: yeah, but it starts moving at that point.

Appendix J

Report on Epistemology of Models Questionnaire

Recall that the 24-item epistemology of models questionnaire classifies epistemic beliefs into five factors: (1) use of models, (2) changeability of models, (3) isomorphic quality of models, (4) features of models, and (5) need for different representational forms of models. Each factor has sub-components, which were rated on a scale of 1 to 5, with 1 being strongly disagree and 5 being strongly agree.

We first administered this questionnaire to three experts, and used their consensus scores as the standard for comparing our students' answers. We accepted agreement within a range of 1 on either side as correct. For instance, if the experts agreed that the answer was 5, we accepted 5 or 4 as correct, while if their answer was 4 we accepted 5, 4 or 3 as correct. In most cases this inclusiveness did not substantially change the overall agreement scores because generally the students' answers were outside of the 1 point margin. (Note: While our 16 case study students answered the pretest questionnaire, only 14 also answered the posttest questionnaire. As such, we used data only from the 14 complete cases).

Analysis of the 5 items

Use of models. Under the first set of questions related to the use of models there were eight epistemic beliefs statements: (1) models are used to show an idea; (2) to explain science phenomena; (3) models are used to physically/visually represent something; (4) models are used to show a smaller scale size of something; (5) to show the relationship of ideas clearly; (6) to make and test predictions about science events; (7) to help formulate ideas and theories about scientific events; and (8) to help create a picture in your mind of the scientific events. Of these, students disagreed substantially with the experts on statements 3 & 4. In both cases there was little or no change between the pretest and posttest answers (item 3, student agreement with experts was 0/14 on pretest, 0/14 on posttest; item 4 had 3/14 on pretest, 4/14 on posttest). Additionally, when we look at individual students three changed their answers on the posttest. While Floyd and Batuk changed to agreement with the experts, Betty's change on the posttest resulted in disagreement with the experts. Strangely, this incorrect posttest answer was more common among her team mates and peers as well. In sum, while the experts indicated that they believe models are not merely used to physically/visually represent something, and not merely used to show a smaller scale, the students predominantly “agreed” that they were.

Changeability of models. There were three epistemic statements related to this main idea: (9) a model may be changed if there are changes in data or beliefs; (10) if there are new findings; (11) if new evidence changes the theory. The students’ pretest answers agreed with the experts (14/14; 13/14; 14/14). If we look at individual answers, we see that though several students made minor shifts within the range of agreement (e.g., moving from 4 to 5) only one student (Ray) made a significant change on item 10 changing from agreement with experts on the pretest (5) to disagreement (1). Given this departure from his peers, and this pretest answer, we can only believe that he misunderstood the question on the posttest, or mistakenly applied the rating scale. By and large, however, these results support the claim that the case study students did not have difficulty with the notion that models can be changed under certain circumstances.

Isomorphic quality of models. There were four epistemic statements related to this main idea: a model needs to be close to the real thing (12) being very exact, so nobody can disprove it; (13) being very exact in every way except for size; (14) being a summary or extract of the phenomenon, emphasizing certain features; (15) giving the correct information and showing what the object/phenomenon looks like.

The biggest change in beliefs is recorded in this set of questions, items 12 & 13. While the pretest showed that the students generally believed that models are isomorphic to the phenomenon (4/14; 2/14), the posttest shows a major shift in this understanding with half the students indicating that they now believe that models do not need to be very exact in every way (7/14; 6/14). Notably, items 14 and 15 also showed changes between the prestest and posttest but none as big. Also, item 15 was the one question where the experts’ answer was in the middle (3) which might indicate that they too had some difficulty with the interpretation of the question.

Features of models. There were four epistemic statements related to the idea of the features selected to be modeled had to be: (16) an exact replica of the phenomenon; (17) show what the phenomenon does and what it looks like; (18) have what is needed to show or explain the phenomenon; (19) represent the phenomenon, as such, it can be a diagram, a picture, a map, graph, or a photo. Once again the question related to beliefs about isomorphism (item 16) showed that students made improvements in this area going from 7/14 agreement with experts on the pretest to 11/14 agreement with the experts on the posttest.

Usefulness of different representational forms of a model. The belief that creating several models of the same phenomenon or object/thing may be useful was articulated into five items: (20) to show different versions of the phenomenon; (21) to show different parts of a phenomenon; (22) to show different perspectives to view a phenomenon; (23) to show how different information is used; (24) to show how each model depends on the perspective taken by the individual who creates the model. Generally, there was no notable change in the individual students' pattern of answers between the pretest and posttest. That said, there were some changes made by Gilles, Ray and Floyd, as well as Nazir, which seemed somewhat odd. In all these cases the students changed to disagreement with the experts. Notably, this was most evident for item 24. Also interesting is that Gilles and Floyd, who both got item 24 wrong, were members of the same team. Once again given their peers' responses, a possible explanation is the misunderstanding of the question or the misreading of the rating scale.

Summary of epistemic questionnaire

In summary, the biggest changes in beliefs were shown for four questions: (12) models have to be very exact, so nobody can disprove it; (13) models have to be very exact in every way except for size; (15) models have to give the correct information and showing what the object/phenomenon looks like; (16) models have to be an exact replica of the phenomenon. What these four questions have in common is the notion of *isomorphism*. These results suggest that students have developed an understanding of the structure of models.

On the other hand, students continued to believe that models must be physical or visual representations (question 3), and that models are used to show a smaller scale size of something (question 4). Though these are both reasonable statements, an absolute agreement with this statement suggests that students have not developed a more sophisticated understanding about the structure of models. These results suggest that students' understanding of the function of models is still fragile.

Though the questionnaire was a good start to determining a student's level of understanding, we believe, it needed to be followed up by other assessment measures. With that in mind, we also asked the students two open-ended questions on the same topic to reveal more about what changes in students' epistemic beliefs occurred, possibly as a result of the intervention. We turn to those data next.

Appendix L