Christa’s Lost Lessons
Newton’s Law

“If the sphere tumbles across here, you can still see the lines.”

Introduction:

The wonder of the Newton’s Laws Lost Lesson is obvious. On board an orbiting spaceship, the absence of gravity has thrilled youth since the age of Jules Verne. In Verne’s 1860s work, From the Earth to the Moon, Jules speculates about the weightlessness of passengers in route to the moon. The amazement comes from the apparent absence of gravitational attraction. Though Newton includes the behavior of gravity among his laws of inertia and motion, the absence of that pulling force seems magical to those who first experience it orbiting the earth. Indeed, what impact do these laws have on astronauts, and how might they be demonstrated aboard the space shuttle? Answering that question was important to Christa and those who conceived these lessons planned for STS-51L.

Background:

Before continuing, read carefully Bob Mayfield’s discussion of the proposed experiment. How the demonstration evolved is, in itself, a useful learning experience teaching the principles of Newton’s laws.

The culmination of the iterative process was a projectile experiment. Two separate balls, a billiard ball and ball bearing are independently catapulted along identical paths. The billiard ball, having twice the mass of the steel ball bearing and twice the diameter, would exhibit twice the inertia. This would lend itself to examining Newton’s Third Law: (F)orce = (M)ass (X)times (A)cceleration.

As Mayfield elaborates, the challenge, in a zero-gravity environment, is the application of like force and direction to each ball’s mass. In order to glean some type of quantitative data, a meter long graduated poster is affixed to the Shuttle’s locker wall. The pair of balls must be catapulted simultaneously in the same direction past the length of the poster. This permits comparative tracking based on equal forces applied to projectiles, one a half the mass of the other.
Below is a video capturing discussion and planning for the catapulting of the balls (spheres) past the meter long backdrop.

**Planning the Projectile Launch Path**

Such an experiment reminds educators of Galileo’s drop of two objects, a feather and an apple, from the Learning Tower of Pizza. Of course, this is often used to confirm another of Newton’s concepts: that the gravitational acceleration is equal for all bodies, regardless of mass. Likewise, science teachers might recall Astronauts David Scott’s Apollo 15 lunar demonstration of dropping a feather and a hammer on the moon. Again, as was the case with Galileo’s experiment, the moon’s gravitational acceleration constant accelerates both objects identically. Both feather and hammer strike the lunar regolith at the same time.

Christa’s lost lesson differs in that the effect of gravity on the billiard ball and steel ball bearing is absent. Only the mass of the objects differs, keeping the applied forces at equal magnitudes. Solving for acceleration yields the result: \( \text{(A)cceleration } = \text{ (F)orce} / \text{ (M)ass} \). Since the force applied to each projectile is equal while the mass of the ball bearing is half that of the billiard ball, the solution has the ball bearing’s initial acceleration twice that of the billiard ball. In order to grasp the difference, a video must capture the catapulting of the balls past the meter long backdrop. Obviously, the ball bearing will quickly outdistance the billiard ball. However, beyond that, the measure of how much is the question? This has to do with the elapsed time since the like force was applied simultaneously for the same amount of time to each ball. Again, use of video would quantify such a result.

Indeed, without gravity, demonstrating Galileo’s experiment is not possible. However, the stripping away of gravity offers the benefit of simplifying the demonstration of Newton’s laws. Comparing Galileo’s and Apollo 15’s experiments with this lost lesson would have been a wonderful science teaching tool.

The idea of eliminating gravity is addressed by Mayfield’s description of a proposed classroom demonstration of Christa’s Lost Lesson. Since gravity acts perpendicular to the movement of an object parallel to the earth, the Newton’s Law Lost Lesson can readily be duplicated on a classroom table.

The class experiment uses the same type projectiles, a billiard ball and a steel ball bearing of half the mass. Additionally, a meter rule is needed. For applying equal forces to the projectiles, some kind of ball point pen spring mechanism is used. These items replicate Christa’s lost
lesson. To assist in quantifying the result as well as providing identical paths and direction, v-slotted planks of wood are needed.

Of course, a video must record the race scene. Positioning the camera on a tripod above the pair of tracks permits later analysis. Video playback would display the pen retractor’s snap launch of the two projectiles as well as their comparative progress versus time along the v-grooved adjacent tracks.

Procedure:

The challenge of applying equal forces for equal times to the projectiles was considerable. The solution is shown above, a release of each ball using a suction system. For the zero-g aircraft practice session, Christa provides the suction on a plastic hose which holds the ball bearing in place until she ceases sucking on the hose with her breath. The demonstration is a rudimentary version of the orbital version. The actual apparatus would include a spring within the tube. Suction holds both projectiles in place and the springs in their coiled positions. Both the billiard ball and steel ball are catapulted by the spring when the suction is terminated. The spring force is equal for both projectiles. Cups of diameters slightly less than each of the spheres hold them respectively in place. Their springs are depressed while suction is applied.

Release of the suction/vacuum pressure permits the two springs to uncoil simultaneously. Though the author has no pictures of the apparatus, it likely was not Christa’s lungs which would have provided the suction.

It is difficult to imagine a device like that displayed in the video. Imagine a pair of tubes, “Y” connected so that one orifice can be sucked on straw-like. Loading the two opposite ends with the two projectiles would require one to suck on the straw vigorously while placing billiard ball and steel ball bearing into their respective cups. While holding one’s breath to keep each projectile snugly seated in its respective cup, Christa would have had to aim each tube in the same direction. Likewise, she would be required to assure each tube held the same position with respect to the meter long poster attached to the shuttle locker wall. Then, with video being recorded, she would cease sucking. This would release the projectiles under spring force. As a
result, they would race across the shuttle interior. Likely, several members of the crew would be needed to collect the billiard ball and steel ball, and, perhaps, an exhausted Christa. Below is the video of the simulated experiment as performed in zero-g.

Christa Sucking on Tube to Hold Steel Ball Bearing in Place
A Classroom Version of Christa’s Newton’s Laws Lost Lesson

The following demonstration closely replicates Christa’s experiment seen in the above video:

Background:

The lost Newton Laws lesson offers students and teachers a mathematical means of demonstrating the law of momentum, derived from Newton’s third law. The expression: (F)orce times the (T)ime the force is applied = (E)quals the (M)ass times the (V)elocity of the projectile. Since force and time is equal in both instances, and the mass of the billiard ball is twice that of the steel ball, the equation when solved for the velocities of the respective balls has the steel ball traveling twice the speed of the billiard ball. The experiment below can roughly confirm the momentum equation derived from Newton’s laws.

Materials:

1. A billiard or golf ball
2. A steel ball bearing or marble half the weight of the billiard/golf ball
3. Two one Meter Long V-grooved 2” by 4” building frame boards
4. Video camera and VCR
5. A small scale for measuring weights
6. Two ball point pen spring assemblies
7. A one meter long scribed poster

Steel Ball Bearing and Billiard Ball on V-grooved Tracks

Cutaway view of spring release mechanism providing equal forces to each ball.
Process:

1. Collect the listed materials. Using a router with a “V” bit, scribe the channel for the ball bearing and billiard ball in the center of each board parallel to the boards’ lengths.
2. Position the boards in lengthwise contact with a yard stick, meter stick, or scribed poster laying lengthwise on the table beside the v-slotted tracks. Have the end of the measuring media coincident with the start of the tracks.
3. Place each ball in the v-groove at the start of the respective tracks. Mount the video camera overhead on a tripod with the camera view centered on the tracks, perpendicular to the plane of the tracks.
4. Start the videoing of the activity.
5. Select two students to release the ball point pen springs by pressing each pen’s release button. (Note: Prior to the actual demonstration, have the students practice snap releasing the springs. This is done to calibrate the application of the applied force. Actually, a single pen spring can be used on the same track to perform the experiment. However, the excitement of a race captures student interest.)
6. Instruct the students how to position their pens’ retractor shafts snugly against each of the balls, assuring the direction of the retractors’ release force is applied through the center of mass of each ball parallel to the surface of the table and v-groove path.
7. Voice a launch count down from ten, instructing the students to press the pen release buttons at the sounding of the “ONE” count.
8. Repeat the process several times.
9. Play back the recorded video of the runs on a television using a video tape recorder. Select for analysis the run which most closely satisfies the criteria described in step 6 above.

Analysis:

The video offers an excellent means of analyzing the experiment. A rough confirmation of Newton’s law of momentum may be made by pausing the view of the progress of the billiard ball and steel ball bearing. Since the frame rate of a video camera is normally about 30 frames a second, each paused view of the track and relative positions of the balls is a thirtieth of a second apart in time. (A playback VCR having a “step-frame” capability is needed.) Based on this, the speed of each ball can be determined using the scribed markings on the measuring device. The speed for each ball can be calculated. The ratio of the speeds should inversely approximate the mass of the two balls.

Questions to Answer:

1. What did you conclude from the results of the analysis regarding the effect of mass on the velocity of a projectile to which a momentary force is applied?
2. What factors might have caused the resulting analysis to fail to confirm the law of momentum when the two projectile velocities were compared?
3. Read Jules Verne’s book FROM THE EARTH TO THE MOON. How did his launch system compare with the experiment above?
4. Can you propose an improved means of applying like forces to the steel and billiard balls?
5. Without knowing the ratio between the two projectiles, how might one determine the mass of the steel ball knowing the mass of the billiard ball using the experiment above?
What Would Have Happened on Challenger?

This question is best answered by actually performing the above experiment. In the process, ask these questions:

1. What added resistance exists on earth, not present for the Challenger demonstration?
2. What danger/peril might one encounter performing the experiment on Challenger not present on earth? Likewise, what danger/peril might one encounter performing the experiment on earth which would not be a factor on board Challenger?
3. Do you believe Christa would have been successful in demonstrating Newton’s Laws as Mayfield describes? Why or why not?
4. How would you suggest changing the proposed experiment to assure a more likely successful outcome? Likewise, what might have been eliminated to assure successful results?
5. What about the filming of the demonstration? Would it have been easier on Challenger or on earth using the video camera and tripod.