CHALLENGER’S LOST LESSONS

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and the STS-51L Teacher in Space Team

(Project: *Space Educators’ Handbook* – OMB/NASA Report #S677)

HARDWARE DEVELOPMENT
FOR TEACHER IN SPACE ACTIVITIES
FLIGHT 51-L

Bob Mayfield with bracketed comments
by Jerry Woodfill

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CHALLENGER'S LOST LESSONS

[**Background:** In 2007, the space shuttle mission STS-118 launched with Christa McAuliffe's backup Teacher in Space candidate Barbara Morgan. Though more than a score of years after the loss of *Challenger's* crew, STS-118 was a reminder of the morning of January 28, 1986. That week Christa McAuliffe planned to perform both live and filmed science lessons. These lost lessons, prepared for the nation and world's school children, were never done. This project delves into those undone educational activities. Indeed, after studying its content, all will appreciate NASA's, Christa's and Barbara's efforts as well as Bob Mayfield's in carefully researching, preparing and training for the performance of the six "Challenger lost lessons." Though *lost* in the sense that they perished with *Challenger* and her crew, recounting, redoing, and examining them is, in a sense, a resurrection. As such, they become a tribute to Christa and her courageous crewmates, the CHALLENGER SEVEN.

Chronology: The happenstance of this editor discovering a copy of Bob Mayfield's, discussion of the six planned on orbit science demonstrations led to the project. Mayfield was a NASA Educational Specialist during the 1980s. His work greatly impressed this author, a spacecraft design engineer. Fascination focused on the extent of the science and engineering performed in the conception, preliminary planning, and earth-based exercises of the *lost six* lessons. Added to this were the mock-up planning practices and zero-g demonstrations of the lessons by Christa, Barbara, Bob, and the NASA team.

Mayfield's narrative descriptions of the apparatus involved in each of the six science experiments were excellent. All were written in the best descriptive technical writing prose. However, not being able to view the described hardware made understanding difficult. The paper did not include sketches. Able assistance from NASA JSC media sources, Mike Gentry, Celeste Wicks and Dr. Jennifer Ross-

Nazzal, the JSC Historian, came to the editor's rescue. They provided both excellent photos and videos of Christa, Barbara, and Bob going through the scripted on-orbit performance of the lost six lessons. Additionally, an internet search found the NASA Educators' Guide for the pair of on-orbit live experiments. The Challenger Center website, founded in honor of Christa and her fellow crewmates, had a .pdf copy of the lesson plan. Unfortunately, the plan dealt only with the pair of live lessons. The proposed six on-orbit filmed demonstrations were not addressed.

Approach: The basis for the project is Mayfield's article on the hardware development of the six lost lessons. To its content, this editor adds photos, video clips, and supporting narrative supplementing Mayfield's observations and writings. These additions are set off in brackets, [….], to distinguish them from Mayfield's work for the JSC Education Office. The editor, using the videos and Mayfield's descriptions, has authored classroom versions of each of the six lost lessons. Often included are sketches and images of the apparatus related to the experiments. To assist the classroom teacher in performing each of the lessons, the scripted experiments are included in the project. They are attached to the body of Mayfield's work and accessed on the CDROM via holding down the *CTRL* key and clicking on the individual items listed above, "hydroponics, magnetism,…etc.". Each includes a materials list, precautionary comments where appropriate, setup, as well as step by step instructions for performing each experiment.

The NASA 1985 publication *TEACHER IN SPACE PROJECT Guide* explains why virtually no follow on material was prepared for performing the six lost lessons in the classroom. The *Guide* states regarding the plans for the six filmed lessons:

Filmed Activities: In addition to live lessons, McAuliffe will conduct a number of demonstrations during the flight. These filmed activities (the six lost lessons) will be used as part of several educational packages ***to be prepared and distributed after the Mission***."

Obviously, because of the loss of *Challenger,* no subsequent *educational packages were prepared and distributed after the Mission*. Therefore, no supporting information was found in NASA literature so that the editor has prepared substitute instructional material (packages), i.e., six substitute exercises replicating Christa's six lost lessons planned for the *Challenger* Mission, STS-51L.

Likewise, no follow-up to the pair of *Live Lessons* ensued. For that reason, this project treats them in the same fashion as the lost filmed demonstrations. However, Mayfield's paper devoted much less discussion to the live lessons. Nevertheless, the archived video content gave them as much attention as those planned for filming aboard *Challenger*. Therefore, they are treated in equal detail in the concluding chapters of this project.

Because much understanding of the lost lessons comes from viewing Christa and others in video clips, the project is recorded on a CDROM able to display Christa's, Barbara's, and Mayfield's actions, words, and findings. In this sense, it becomes a worthy substitute for Christa's planned on orbit filming of the six lost lessons. Using the CDROM, educators can replicate that which Christa was not able to share from orbit. But, fortunately, her wonderful teaching gift and spirit are captured on video tape. Though performed both on earth and in NASA's zero-g aircraft rather than on orbit, Christa's remarks and actions in training for the six experiments accomplish most of her lesson plans.

While more than a score of years have passed, her often quoted remark is once more validated through this project, "I touch the future, I teach". Students experiencing the six lost lessons will fulfill Christa's prophetic words. They are the future touched by Christa's teaching gift. May all who participate in this project know the same warmth and admiration for Christa as those who selected her as NASA's first teacher in space**.]** **JRW – Houston - 2007**

HARDWARE DEVELOPMENT FOR TEACHER IN SPACE ACTIVITIES FLIGHT 51-L

By Bob Mayfield

Hardware design and development began at Johnson Space Center in August 1985. Although a number of people contributed to the proceeds, a talented team of engineers from Pan American Engineering and the personnel in the shops at Johnson Space Center comprised the backbone of the process.

The Teacher in Space Project (TISP) involves six activities which will be filmed and photographed during the mission and two live lessons aired on flight day 6. The six activities are listed below in the order in which they will be conducted. A discussion of some of the rationale for the hardware design follows: [The following are henceforth identified as *the lost six*.]

HYDROPONICS

MAGNETISM

NEWTON'S LAWS

EFFERVESCENCE

CHROMATOGRAPHY

SIMPLE MACHINES

Before discussing each activity, it is probably appropriate to relate some of the general constraints that applied to the payload in general. First, it had to fit within the confines of one mid-deck locker (approximately 17"x14"x22"). It had to pass off-gas tolerance criteria. This eliminated or restricted the use of many plastics, metals, adhesives, and liquids. Obviously, it had to be safe and not interfere with the operations of the Orbiter's systems. Also considered was the flammability of the materials independently and collectively. Other constraints were established by the perceived goals of the project. For instance, it was important that teachers in the classroom would be able to closely duplicate the equipment and conduct demonstrations to be used as a comparison of the behavior of phenomena on Earth and on-orbit. It was believed that highly exotic hardware would inhibit the involvement of some teachers and student groups. The range of age levels had to be considered. The action, interaction, or reaction of components had to be clear in order to be filmed and photographed. Finally, the number and variety of the activities, plus the equipment to support the live lessons precluded the possibility for the education staff to develop viable quantitative science experiments of each activity in the time allotted to produce the hardware. Therefore, the activities had to be considered qualitative demonstrations.

HYDROPONICS

The goal of the hydroponics activity was to demonstrate a possible procedure that might be used on the Space Station and in future space endeavors to provide nutrient requirements in a closed environment in microgravity. The objective was to demonstrate the processes related to growing plants in microgravity.

The lesson plan called for two white beans to be germinated per day beginning 7 days prior to launching. One plant from each pair would have been selected for flight, contained in its own closed hydroponics system.

Several problems emerged. White beans take several days to germinate. They produce large plants quickly after emerging. The absence of good light for plant growth on the Orbiter would have aggravated the latter problem by causing the plant to be "leggy" or elongated. There would not be room in the locker to accommodate adequate containers. Mung beans had better characteristics and had been flown on a previous mission, providing some baseline information. The number of plants was reduced to six due to payload volume constraints, and it was decided to use three seedlings 2 days old and three newly germinating seeds to reduce the overall time involvement by ground support staff with this single activity.

Hydroponics in Space Lesson

Aboard the Zero-G Aircraft, Christa Applies Misting to Chamber 6 which will hold a Mung Bean

Another major problem was that of providing a substrate for the plants that would allow for growth while keeping the fertilizer fluid where it belonged. A number of ideas were tested with the help of volunteers such as Cheryl Barnard, an undergraduate student at the University of Houston, and John St. John, an eighth grade student from Friendswood, Texas, The final design consists of a 1/2-inch layer of polyester fiber sandwiched between two lexan rings. Nylon mesh was glued to the upper side of the bottom ring to hold the fiber. The rings are separated by two stainless steel tubes 1/2-inch long. Two screws fit through the tubes to hold the platform together. Two longer screws secure the platform to the top of the 2-inch diameter cylinder. The seed is nestled into the fiber. This configuration was accepted for its relatively simple design, keeping in mind the fact that to be cost effective on a large scale, such as in the Space Station, the simplest workable system would be desirable.

Hydroponics Chamber

Another aspect of this activity is the root misting apparatus in cylinder number six. This idea was stimulated by experiments at the Epcot Center. The roots of the plant in this cylinder will be misted once a day. If this plant remains as healthy as the others, perhaps such a weight saving system could be employed on a large scale in the Space Station.

Close View of Hydroponics Experiment Apparatus

MAGNETISM

The goal of the magnetism activity was to understand the role of magnetic lines of force in the space environment. The objectives were to photograph and observe demonstrations of magnetism in space, and to photograph and observe lines of magnetic force in three dimensions in a microgravity environment.

A compass and bar magnet readily procured from a teacher supply store were selected to demonstrate that magnetism certainly is a force in microgravity. The magnet had to be stripped of its plating material and nickel plated to make it pass off-gas criteria.

Magnetism Experiment Ground Practice

A box made of aluminum or some other nonferrous material, holding iron filings, and covered by a transparent top was proposed as a means of demonstrating lines of magnetic force in two dimensions. It soon became clear that a sandwich of two lexan plates separated by a "gasket" of lexan would occupy less volume and be easier to fabricate. Two tiny holes were drilled in one plate to preclude problems of pressure differential in case of a contingency EVA causing the cabin pressure to be lowered. Safety considerations precluded the use of iron filings which might have been ingested by crewmembers or electronic equipment if accidentally released into the cabin. Instead, soft iron wire (baling wire) was cut into lengths 1/8- to 1/4-inch long for use in this and the other magnetism demonstration. These wire pieces had to be coated with nickel oxide, soaked in oil, then baked to prevent rusting. They were also tumbled with ball bearings 24 hours to remove sharp edges. Some tests were done using #6 steel shot, but the linear wire pieces gave the best results.

The original proposal for demonstrating lines of force in 3-D called for a transparent beach ball with an electromagnet suspended inside. An exhaustive search for a suitable ball was futile. Therefore, a cube was constructed of the same material found covering the drink containers used on the Shuttle. Tests proved its optical qualities were acceptable, it was tough, and could be bonded using equipment at the Johnson Space Center. It was believed that the cubic shape would cause the least problems with reflections during filming.

The electromagnet evolved out of much testing of suitable core materials, wire sizes and lengths, and battery configurations. The final product consists of 400 feet of copper magnet wire around a 3-1/2 inch soft iron bolt 1/4-inch in diameter. The resulting magnet is 3/4 inches in diameter. Soft iron does not retain magnetism when the power is turned off. Power is supplied by two "AA" batteries wired to a toggle switch with built-in LED, and a variable resistor with a range of 0-250 ohms.


Magnetism Lines of Force in Space Lesson

Though this electromagnet is not strong enough to hold the wire pieces in 1 g, tests on the KC-135 weightless trainer proved its effectiveness in microgravity conditions. A more powerful magnet was not used to preclude interference with the Orbiter systems.

An additional problem to be addressed was the introduction of moisture from the breath as the cube was inflated. The resulting condensation obscured viewing into the bag and caused rusting on the approximately 4000 wire pieces inside. Solving the problem included treating the wire as previously described and putting a desiccant filter in the inflation tube.

NEWTON'S LAWS

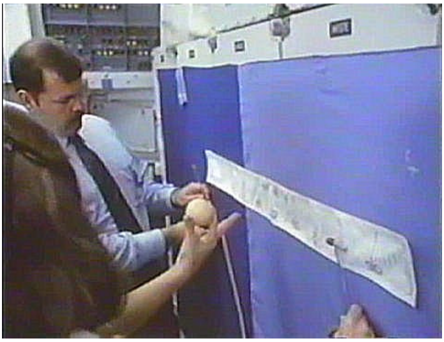
The goal of this activity was to demonstrate the fundamental laws of motion during weightlessness. The objectives were to show the principle of inertia in an orbiting spacecraft; to show the relationship between force, mass, and acceleration; and to show the action-reaction of two different masses colliding.

To first demonstrate that objects have no apparent weight .in the spacecraft was relatively straightforward; an object would be suspended in midair on a small spring. The spring would not stretch because the object is in free-fall around the Earth traveling at the same rate as the spacecraft. If the end of the spring were attached to the inside of the craft and a thruster were fired, it would cause the spring to stretch due to the spacecraft changing velocity with respect to the object.

Determining how to demonstrate the objectives was not so straight-forward. Historically, educators have disagreed on methodology for treating this topic.

Add the educated opinion of engineers and technically oriented support staff to the realities of the Orbiter environment and the problem became very complex.

There was discussion of using objects such as wooden blocks of different sizes, therefore different mass; except some of the activity called for objects of the same size, yet 1/2 or 1/4 of the mass of each other. This would have meant finding materials whose densities varied with the desired proportions, or mechanically altering (drilling holes) in one of the objects to achieve the desired effect. The wooden block idea sounded plausible until flammability and off-gassing were considered. Using metal blocks was considered and dismissed, remembering the criteria of keeping the hardware within the ability of teachers and students to copy as closely as possible. Overall payload weight (pre-launch) was also considered - metal masses large enough to be filmed effectively would have been relatively heavy, even using aluminum. Another problem with blocks would have presented itself when the teacher attempted to use whatever triggering device was developed to exert a force on the object. If the forces were not exerted precisely through the center of mass of the block, it would tumble and not move as desired. A sphere would not present this problem.



The decision to use spheres created a new challenge: making spheres of common substances acceptable for flight in a manner available to the public. The challenge was met by acquiring a billiard ball, then locating a steel ball bearing whose mass was almost exactly 1/2 its mass. Conveniently, the diameter ratio of the spheres was almost exactly 1 to 2 also. The ball bearing used was 1-1/8 inches in diameter.

Another problem to address was the force actuator or trigger device. Some means had to be provided for the teacher to apply the same amount of force to different objects accurately, repeatedly, without imparting other influences.

Using the retraction mechanism of a ball point pen was considered. This posed difficulties. Though the teacher would be able to exert the force through the center of mass of the sphere easily, it would prove difficult to aim the pen while holding it next to the ball before triggering it to send the ball along the desired path. Remember, this would be performed while the demonstrator and the ball were free-floating, subject to air currents set up by the ventilation system.

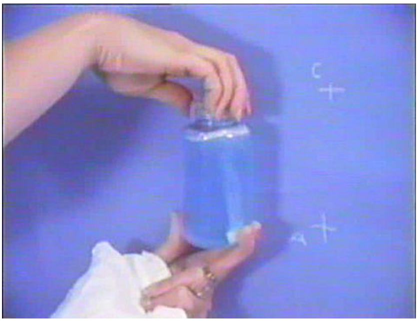
The resulting actuator uses the vacuum created by suction on a tube to hold the ball against a flexible cup. The ball compresses a coil spring protruding from the center of the cup. Thus captured, the ball may be aimed accurately so that it will follow the desired path in front of the cloth metric measure strip that will be Velcro attached to the 4'x 6' backdrop affixed to the mid-deck locker doors to improve visibility of objects during filming. Using two different springs and the vacuum system the teacher can release the spheres at the same time, using the same force repeatedly.

Ball point pen retractors or something similar may be used in 1 g on a billiard ball and ball bearing sitting on a level table or on a V-groove track to duplicate this activity in the classroom.

EFFERVESCENCE

The goal of the effervescence activity was to understand why products may or may not effervesce in a microgravity environment. The object was to show the action of bubbles produced in a microgravity environment and to observe the lack of buoyancy. The activity originally called for a clear plastic container, open on top, an effervescent tablet, and a water gun. The teacher would have placed the tablet in the container, then used the water gun to add water. This scenario presented several concerns to the safety board and engineers. Though one of the Skylab crews demonstrated that water could be squirted .into an open container using their food re-hydration water gun, they had good control of the forces acting on the water, i.e., the release of liquids into the cabin. Errant fluids pose a threat to electronic systems in the Orbiter. The container would have to be covered. Glass containers were undesirable due to possible breakage. The search began for transparent bottles of adequate size, clarity and acceptable material. A standard drink container with a tablet sealed inside was tested. Filming the action was difficult, and the pressure generated by the carbon dioxide gas caused the water to be ejected from the septum. Some means had to be developed to accommodate the CO2 and allow for air displacement during filling in cases in which a hard walled Plexiglas container was considered. Finally, a transparent lexan bottle was discovered that proved to be the solution to this and other hardware puzzles. Lexan is tough, transparent, and flight approved. There would be no concerns about off-gassing or breakage. Pressure tests proved the bottles able to maintain a seal to at least 60 psi, and the tablets generated somewhere in the range of .2 psi.

Modifications on the bottle include the addition of a Teflon gasket in the lid, and a viton diaphragm glued over the mouth. The diaphragm has a slit to accommodate insertion of the effervescent material, and functions as a barrier for the water while the lid is off. The water in the bottle is colored with blue food coloring to enhance visibility.



Left picture of Christa inserting the tablet into cap-slot

Right photo is of Christa screwing on lid while tablet effervesces

The last component of this activity to be discussed is the effervescent tablet. A commonly available tablet will be used, but it will be crushed and the powder enclosed in water soluble gelatin capsules that may be purchased at a pharmacy. The capsule is perforated by 60 holes.

Several concerns led to this arrangement. The first was safety. It is not as simple to insert an unprotected tablet through the slit in the diaphragm as one might believe. The small amount of water that will be present on top of the diaphragm when the lid is removed begins to dissolve the tablet immediately allowing water to escape, and preventing observation and filming of the object. That portion of the tablet that enters the bottle then reacts quickly so that observation and study are hindered. It is hoped that the perforated capsule will allow the desired results to be achieved while slowing down the reaction time of the chemicals.

CHROMATOGRAPHY

The objectives of this activity were to demonstrate chromatographic separation of pigments and capillary action in microgravity. This activity was originally part of the hydroponics demonstration, though in that case, capillary action and osmosis would have been observed instead of chromatographic separation. The original plans were changed primarily because of the complexities they created in the design of the hydroponics chamber. Time was a critical factor driving the selection of off-the-shelf equipment and design, testing, and fabrication of all the hardware for this project. Thus, a chromatography activity emerged.

Chromatography in Space Lesson

Tests with various inks, papers, and quantities of water promised this to be an easily duplicated demonstration for the classroom. Place a spot of ink on a piece of paper, hang the paper on the bulletin board, add a drop of water, and observe while the water dissolves the ink. The water moves against gravity due to capillary action, carrying the components of the ink with it. These components are deposited in layers or strata, much like sediment in a river, according to their molecular mass and the size, shape, and charge of their molecules.

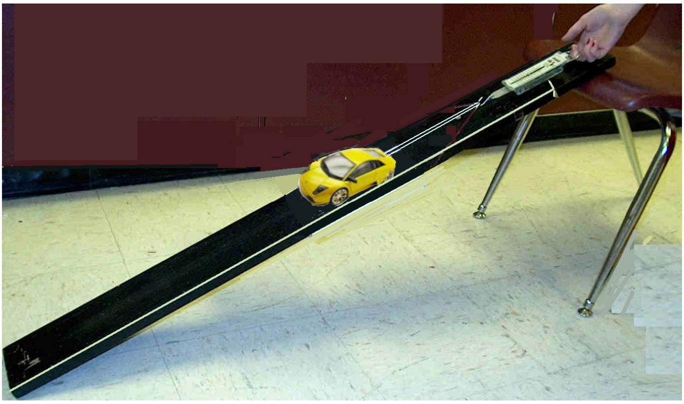
The teacher will use strips of filter paper 1/2"x 3" long, and a flight approved, water base ink felt tip pen. The paper will be placed in a lexan vial after adding a water drop to begin the process. This prevents evaporation from slowing down and stopping the process prematurely.

There are parallels between the behavior of the ink molecules in this demonstration and the behavior of the molecules of the chemicals used in the continuous flow electrophoresis (CFES) used to process pharmaceuticals.

SIMPLE MACHINES

The objective of this activity was for students to understand similarities and differences between the use of simple machines in space and Earth environments. The question posed was "would certain simple machines have been developed by people who always lived in microgravity?" Stated another way, "what are the applications in space for simple machines like the wheel and axle, lever, inclined plane, wedge, and pulley?"

The original plan called for a wooden inclined plane, a cart with four wheels, hammer and nail, screw to be screwed into the inclined plane, and a pulley. The commander immediately vetoed the idea of driving nails into the wood because of the potential for damage to the Orbiter". A refresher in physics reminds one that the forces input into the hammer-nail-wood system would ultimately have to be transmitted to either a crewmember or the craft. Since the goal of this particular part of the activity was to use the hammer to pull the nail, thereby demonstrating a fulcrum and lever, it was decided to demonstrate the lever using the 18" pry bar in the Orbiter tool kit instead. Also, it was not desirable to use wood due to flammability. For some time a 4" wide folding aluminum meter measure was considered to serve as an inclined plane and with the Newton's Laws demo, but it proved to be a stowage problem. A wedge of aluminum 10" long x *2"* wide x *3"* high was produced to serve as the inclined plane and wedge. It also was drilled and fitted with an insert to provide friction for a screw that the teacher will use to demonstrate the use of a simple tool, the screwdriver, in space.



A pulley will be attached to the mid-deck locker and used to pull a small car "up" the inclined plane. This demonstrates that the wheels are useless on the car, lacking friction with the plane, but that the wheel functions well as a pulley to change the direction of a force. Of course, multiple pulleys could be used to multiply a force to assist in moving mass in microgravity.

* * * * * * *

[*While the following live planned demonstrations were excellent planned exercises utilizing Christa's teaching gift, they differ from the previous six lost lesson in content and approach. The previous six were not to be conducted "live" but rather recorded on film or video. Additionally, the* ***Lost Six****, are more fully addressed in Mayfield's paper. This enabled the author to more specifically duplicate their planned execution. Likewise, the* ***Lost Six*** *had, in most cases, available NASA archival videos. These recorded training exercises were both on the ground as well as on board the zero-G KC-135 NASA aircraft.*

The live lessons are discussed below in summary manner by Bob Mayfield. Thankfully, there is a video of Christa's "walk though" of a portion of the live lessons. The pair of live lessons are *also revisited in this project.. Indeed, as Christa often said, "I Touch the Future. I Teach." Through the lost live lessons, she will be teaching once more, though more than a score of years since that momentous launch of January 28, 1986*. JRW November 2007]

Challenger's Live Lost Lessons

WHERE WE'VE BEEN, WHERE WE'RE GOING (SECOND LIVE LESSON)

On flight day 6, the teacher will conduct two (2) 15 minute lessons broadcast live from the Orbiter. The first, titled "The Ultimate Field Trip," required no special hardware. The goals of the second lesson were to better understand why mankind utilizes and explores space. The objectives were to demonstrate the advantages of manufacturing in microgravity, to highlight technological advancements that evolve from the space program, and to project mankind's future in space. It was particularly desirable that these demonstrations could be duplicated in the classroom so that students could compare in real time the results of what they did to the space activity.

Several demonstrations will be conducted to illustrate the behavior of materials in microgravity. A sphere of orange juice will be formed carefully from a drink container. The fact that liquids form perfect spheres in space is useful in forming mono-disperse latex beads, for instance, which can be used by the Bureau of Standards. Mixing of molecules of different substances will be illustrated using marshmallows and chocolate candies in a plastic bag. Mixing of liquids of differing densities will be demonstrated using salad oil and colored water sealed in lexan bottles. Two of these containers will be used. One has 1/2 water and 1/2 oil. The other contains 1/3 water, 1/3 oil, and 1/3 air. These can be compared to determine how the presence of the air affects the way the liquids behave. A marble is in each bottle to stir the mixture. Also, the teacher will use a large quartz crystal to discuss the special conditions conducive to the growth of large crystals, especially relating to the growth of crystals in space. Of course mankind uses space for more than materials processing. This will be illustrated using 8x10 color photographs of phenomena visible on the Earth from space, but not so apparent on the ground, or even from aircraft. A photo of a hurricane, a volcanic eruption, a large meteor crater are three (3) examples of the Earth activities man monitors from space.

Additionally, the teacher will have a photo of the Hubble Space Telescope planned for launch in 1986, and the Voyager space probe which will be at its closest encounter with Uranus in January 1986.

Finally, a scale model of the Space Station has been constructed to demonstrate the modular concept which will be employed to construct America's permanent Space Station scheduled for deployment beginning in the early 1990's.

This concludes the discussion of the hardware development process for the Teacher in Space Project. Limited by available time and other factors, the author could only hit the high points in most cases in his discussion of the individual items that comprise the payload for the project.

Special thanks need to be extended to a number of people who contributed a great deal of their talents and time to ensure the success of this endeavor. Among them are Charles Chassay, Payload Integration Manager at the Johnson Space Center and Sonne L. Hooper, Supervisory Engineer of the Engineering Support Services Branch of Pan American Aerospace Services Division, Houston, Texas. Their guidance and insight were invaluable. The primary Pan Am team of Gary Green, Joe Bufkin, and Marilyn Gragg, were most patient and helpful throughout the process. There was a true spirit of teamwork among all involved.

Finally, thanks to the Teacher In Space finalists who provided the ideas, the raw materials, which were used to construct these valuable teaching tools.

Bob E. Mayfield, Hardware/Procedures Coordinator, NASA/AESP
Johnson Space Center
Houston, Texas
January 9, 1986

[For a preliminary or concluding review of the video performance of the six lost lessons, click here (*Ctrl* key down) or on the frame below:

Added comments about the *Challenger* Lost Lessons Project:

Unfortunately, most of the pictures included in text of the paper are rather fuzzy compared to what most expect with today's digital photography. Using software capture techniques, this paper's photos were gleaned from video scenes of Christa and her team practicing the six lost lessons. Even after applying "touch-up" sharpening algorithms, the quality was less than good. However, were it not for the existence of these videos among Johnson Space Center's video archives, this work could not have been accomplished.

At this writing, no sketches or drafted drawings of any of the apparatus employed to practice the lost lessons have been uncovered. All analysis of the science, technology, and spacecraft engineering devoted to the planned STS-51L lessons comes from Mayfield's paper, the videos, a few existing archival photos and the author's interpretation of audio comments accompanying the videoed exercises. Also, as a practicing spacecraft electrical engineer for more than forty years with NASA, the author has drawn from his background with similar space borne scientific experiments and engineering projects to assist in understanding the trials and potential pitfalls of the six lost lessons. In some cases, one wonders if the actual performance of portions of these exercises would have been successful on orbit. Indeed, they are altogether innovative and, at times, complex in choreography, especially in a zero-g environment. Watching the zero-g trials performed by Christa, Barbara and Bob in NASA's KC-135 speaks to how very demanding they might have been. But that is what CHALLENGER was about, the *challenge* of "touching the future" by a teacher named Christa McAuliffe.]

Jerry Woodfill, Editor

THE LOST HYDROPONICS CHAMBER LESSON

"It's the one on the right."

Background Science Summary:

Because the definition of hydroponics is growing plants in liquid nutrient mixtures without soil, application in space is advantageous. The only soil found in low earth orbit is brought by the spacecraft. Having Christa perform a hydroponics experiment was attractive because of the simplicity of the apparatus required. However, there was a unique innovation included in Christa's lost hydroponics lesson. It dealt with the misting of one of the plants among the six mung beans in the chambers of the apparatus. The question was: Would misting serve equally well as immersing the plants in the fertilizing nutrient solution? If so, much less mass need be launched into orbit, saving many dollars based on the cost per pound to place objects in low earth orbit.

Christa Planning Hydroponics Chamber in Space Demonstration
Hold down CTRL Key and click on:
hydroponic_ground_practice.wmv

In the above video, Christa deals with planning the best location for the hydroponics chamber based on expected lighting conditions in the Orbiter for photography. Because plant growth might be affected by available lighting, this was an important consideration. With only seven days for plant growth during the mission and limited lighting, the six mung beans were given the opportunity to germinate, as well as for three of them to grow for two days prior to launch.

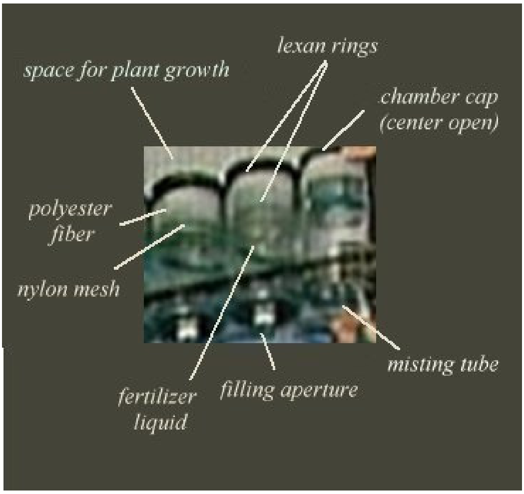
Christa, Barbara, and Bob Mayfield practicing the Hydroponics Chamber Lesson in NASA's zero G aircraft.

Hold down CTRL Key and click here.

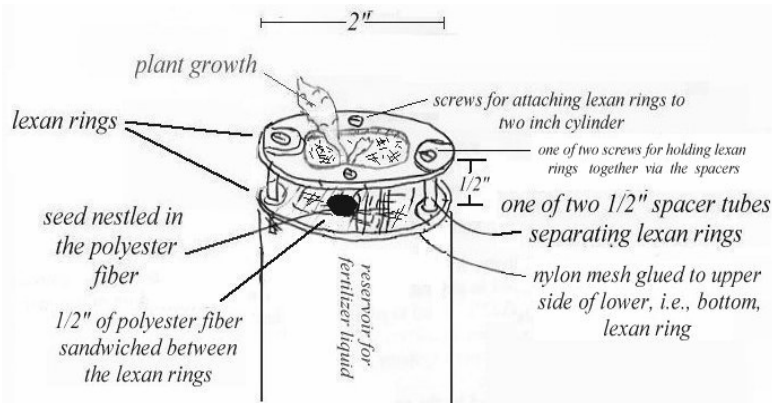
The photo above is extracted from the Zero G practice session with the hydroponics chamber. The exercise appears to be dealing with setting up the “misting” procedure, i.e., the spraying of the fertilizing nutrient into chamber six, apart from the remaining five chambers containing liquid fertilizer.

The photo below is cropped from Christa’s zero-G exercise with the hydroponics experiment.

The Hydroponics Experiment Apparatus



Editor's Interpretation Based on Bob Mayfield's Description



Editor's sketch based on Mayfield's description of a single hydroponics chamber

Hypothesis:

The explanation written by Bob Mayfield is an excellent summary of what Christa might have demonstrated aboard Challenger using the hydroponics chamber. The class project which follows replicates the on-orbit experiment with materials readily obtainable from local stores. After constructing the six chambers, the six mung seeds are treated exactly the same way Bob Mayfield describes them being treated prior to launch and during the one week mission.

By continuing the experiment for a period of seven days, with misting of chamber six once per day, Christa's lost hydroponics chamber experiment may be performed in the classroom. Above is a sketch of the *Challenger* experiment based on the previous photos and Bob Mayfield's description.

Because the class experiment is performed in a one-g environment, the apparatus is much simplified from that seen above. The volume above the emerging plant stems need not be enclosed, i.e., the leaves may simply droop over the edge of each chamber. Additionally, there need be no lexan ring holding the one half inch mesh of polyester fiber in place.

The proposed experiment, as addressed in Mayfield's paper, only spoke of the mung bean nutrient as a fertilizer. No chemical composition was suggested. However, based on the vigorous growth of the mung bean, water may be employed as long as it has a ph suitable for growth. Any bottled water from a grocery store should be appropriate. Even tap water might be used. The class can experiment with an altered nutrient solution by adding Miracle Grow, sugar, or other additive to the nutrient solution. Nevertheless, whatever is chosen, it is important to employ the same solution in each chamber as well as the misting liquid sprayed into chamber six.

The vigorous growth of the mung bean during the pre-gemination stage requires little or no light so that the limited lighting in the space shuttle crew quarters.

Materials:

1. Six clear plastic empty 20 oz. soft drink containers
2. One of the six containers has a hole drilled in the side near the chamber bottom for atomizer insertion and root misting.
3. Bandage Gauze from Drug Store
4. A pound of mung Beans
5. Atomizer for misting the roots of the chamber six plant once per day
6. Clear adhesive tape encircling all six containers so that they are inline for viewing, photographing and performance of the experiment
7. Scissors
8. Adhesive labels, one per chamber
9. (Optional) Digital Camera record of daily growing progress.

Procedure:

The greatest challenge is constructing the six hydroponics chambers. Five are identical with the sixth differing in having a hole made in its side near the bottom in order to spray fertilizing nutrient into its root system once per day.

The pictures which follow depict the steps for converting each of the six 20 oz. soft drink bottles into a hydroponics chamber:

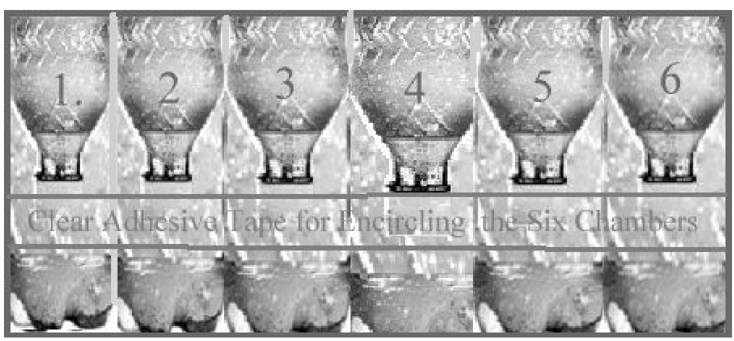
1. Empty the bottle of soda/spring water and thoroughly clean it, rinsing it with tap water.
2. Remove all labels so that the insides can be clearly viewed.
3. Remove the cap and discard it.
4. With scissors cut the bottle into two sections as shown. Caution: Have the teacher or an adult do this by first puncturing the bottle at the desired cutting point. Insert the sharper of the two scissor blades into the puncture and begin cutting around the circumference perpendicularly to the bottle's length.
5. Rotate the top half of the plastic bottle 180 degrees and insert it into the open mouth of the bottom half.
6. With adhesive tape, secure and seal the two halves at the seam to keep the chamber from leaking. Fill the chamber with water to test the seal. Add more tape if water leaks from the seam.
7. Affix an adhesive label, numbering the chambers in order from one to six.
8. Repeat the above steps for five additional chambers.
9. For the sixth chamber, puncture the chamber's side approximately a half inch from the bottom with the sharper blade of the scissors. Cut a half inch diameter hole starting at the punctured opening. (**Caution**: Have your teacher or an adult cut the hold for spraying nutrient into the root system once per day.)

After each daily spraying of the roots, tape closed the access hole with clear adhesive tape.

10. Tape around the entire collection of six chambers so that they assume a horizontal in line configuration.

1. Select Bottle
2. Remove Label
3. Remove Cap
4. Cut Bottle
5. Insert Top
6. Tape Seam

(ABOVE FIGURE: A DEPICTION OF THE PROCESS USED TO CONSTRUCT THE HYDROPONIC LOST LESSON CHAMBERS)



Hydroponics Chamber of Six

11. Fill the first five bottles with the fertilizing nutrient solution up to the level where the upside down neck flares out.
12. Stuff the gauze into each bottle forming a layer one half to one inch thick above the neck making certain some of the gauze is wetted by the nutrient solution.
13. Shake the bottle vertically so that the gauze becomes damp and contacts the liquid.

14. After two days of germinating three mung beans small sprouts should show. Place the three plants respectively in the gauze of chambers one, two and three. (Note: These have geminated from seedlings such that once a sprout appears the geminated mung beans continue to be in contact with the solution for forty-eight hours before placing them in the hydroponics chambers.) Place three un-geminated, i.e., mung bean seedlings (that have been in a nutrient solution for three days) in the gauze in the remaining three bottles, nesting each bean into the damp gauze.
15. Place the hydroponics chamber in the window or outside in the Sun during the day. (Note: the pre-germination of the three mung bean seeds can be accomplished simply by allowing them to begin the experiment three days early giving them an overall nine days in the nutrient solution.)
16. Take a photo of the six in line chambers with the digital camera.
17. At the same time each day, take a picture for a period of seven days.
18. After each day's picture taking, spray nutrient liberally into chamber 6 so that the mist thoroughly saturates the volume of air beneath the gauze in chamber 6.
19. Measure the length of the plants above the gauze and determine other characteristics each day. Finally, record your findings along with a printed copy of the daily chamber picture.

What Would Have Happened on Challenger?

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

1. How would the absence of gravity have affected the apparatus designed for the classroom?

2. What impact would ambient lighting onboard *Challenger* have compared to classroom lighting?
3. Based on classroom plant growth over seven days, was the hydroponics chamber design adequate to contain the plant volume produced?
4. Do a report on the characteristics of the mung bean. Why was it a good choice for the *Challenger* hydroponics demonstration?
5. Would the hydroponics chamber grow plants in the Shuttle's cargo bay…why or why not? Discuss.
6. Finally, examine the STS-118 Educator in Space Mission which dealt with the same considerations for building a classroom hydroponics chamber. What makes it more doable and less complicated than the hydroponics lost lesson proposed for Christa on STS-51L?
7. Compare Christa's Hydroponics Lost Lesson Chamber with the commercial Plant Growth Chamber carried to the space station for the hydroponics lesson planned for students after STS-118. How does the commercial chamber [adapted from a ground based chamber for the space station experiment] compare with Christa's?
8. Compare the STS-118 choice of basil seeds with STS-51L's mung beans. Would basil seeds have worked better or worse for the *Challenger* Hydroponics Loss Lesson? Why or why not?

FOR TEACHERS ONLY: An actual in space hydroponics experiment growing mung beans was conducted on STS-3 so that the *Challenger* Hydroponics Lost Lesson was partially validated earlier. The class need not know this prior to answering the above questions. However, the following was reported concerning the STS-3 experiment: "Mung bean seeds were grown in a plant growth unit on STS-3. After eight days of microgravity, most of the seeds germinated and grew as tall as the 1-g standards; a few plants appeared to become directionally disoriented."

THE LOST MAGNETIC CHAMBER LESSON

"Oh! I think it will do it (*work*)."

Background Science Summary:

Among the lost lessons, having Christa perform a science magnetism experiment in space was unique. Studying the orientation of magnetic lines of force in a zero-G environment promised to be a fascinating lesson. Perhaps, the most clever of experimental props was the above three dimensional magnetic chamber.

Though Christa's experience and training dealt primarily with social sciences, her perceptiveness was apparent in suggesting refinements in how experiments and demonstrations were to be performed. The ground based trial of the lost magnetism lesson is an example.

A brief primer on magnetism explains the existence of molecule and sub-atomic particle alignments in matter creating like and unlike magnetic forces. The demonstration of magnetic attraction was conducted by Christa at the first of the ground based practices held at Johnson Space Center. Click below the picture to view the video.

Christa Practicing Bar Magnet in Space Demonstration
Hold down CTRL Key and click on:
bar_magnet_demonstration.wmv
The video is played in Media Player.

In the above video Christa deals with the term poles, i.e., north and south, showing the characteristics of attraction and repulsion of unlike poles and like poles of a bar magnet. The existence of the Earth's magnetic north pole has guided mariners long before Columbus sailed the ocean seas. The string was to assist in the one G on Earth practice of the demonstration. Suspended in zero-G, the bars would come together and separate without the need of the supporting string. Bob Mayfield explains the need for the string for this practice.

Hypothesis:

The explanation written by Bob Mayfield is an excellent summary of what Christa might have demonstrated aboard Challenger using the magnetic chamber. The cubicle test bed holding the specially manufactured metal particles certainly would have shown the three dimensional nature of a magnetic field.

Materials:

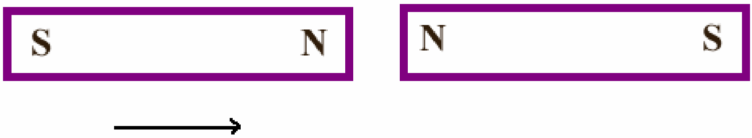
1. Pair of bar magnets and string
2. Compass
3. A plastic half liter empty clear soda bottle (16 oz.)
4. Plastic test tube sized about 3/4 the bottle height and with a diameter capable of allowing item 5's axle-like insertion into the test tube.
5. A cylindrical magnet for insertion into the test tube, perhaps, a cow magnet or a stack of Radio Shack button magnets inserted in the tube.
6. A roll of masking tape.
7. And, of course, iron filings from a science museum or scientific experiment supplier.
8. (Optional) video camcorder with flip out playback screen
9. (Optional) digital still camera

Procedure:

(Optional: Have an assistant video tape the procedure just as Christa was video taped.)

The previous photo captures Christa performing a bar magnet demonstration. This experiment is easily done in a classroom. Before continuing, watch the video clip several times, listening carefully to Christa and Bob Mayfield's comments. (Click here while holding the *ctrl key* down to view the video.)

Actually, the video of Christa's bar magnet ground demonstration is an excellent learning tool not only magnetism but also Newton's laws. Tie a string to the center of one of the bar magnets as shown in the above photo. Next bring like poles in close proximity, and note the rotation of the hanging magnet about its center, suspended from the string. After placing one of the bar magnets on a table, slide the other bar magnet toward it so that like-poles come into close proximity. Assure the pair of magnets are aligned and parallel as shown below.



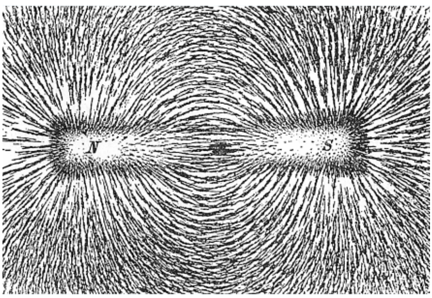
Move Left Magnet's North Pole
toward Right Magnet's North Pole

Observe the movement of the right magnet in a line rather than rotating. Consider why the former trial caused the suspended magnet to spin while the latter case only moved the magnet linearly. Christa and Bob Mayfield discuss the expected results conducting the demonstration in orbit compared to their earth-based experience, knowing that no string will be required to suspend the bar magnet in zero g.

Christa practices demonstration to show lines of force in zero-g

This leads to the lines-of-force bar magnet demonstration captured in the above picture of Christa as well as the video. Obviously, Christa's practice has the orientation of the white background planned for zero-g rather than a one-g classroom environment. Though this facet of the bar magnet demonstration was not specifically described in Mayfield's paper, it is useful as a lead-in to the magnetic chamber experiment which follows. Perhaps, for that reason, Christa, Barbara and Mayfield practice it.

Based on the video and the above photo, it is obvious Christa plans to use Velcro to attach the white placard background to the wall of the Shuttle. Likewise, she positions the bar magnet in the center of the placard while speaking of the lines of force which will be observed emanating from the bar magnet and displayed on the white background. The expected pattern is shown in the picture below.



Expected lines of force geometry to be displayed during the *Challenger* Lost Magnetic Lesson Demonstration on orbit.

However, it is known how iron filings would behave in zero gravity. Simply watch them hurl about the enclosed magnetic chamber during the KC-135 practice by clicking here holding down the ctrl key. This leads to the assumption that the application of iron filings to Christa's bar magnet held against the white background must be accomplished in a closed container. Though no such container has been described or sketched by Mayfield, there are similar educational props available which suggest the design. They consist of a clear thin sandwich-like enclosure which lend themselves to having a bar magnet placed on them. In fact, a large rectangular "zip-lock" bag would serve the purpose quite well.

Yet, there might have been another approach intended for Christa's on-orbit bar magnetic lines-of-force demonstration. Once the electromagnet chamber was inflated, one of its sides might have been brought into proximity to the bar magnet/placard Velcro attached to the wall. Christa might have held the chamber's side flush against the placard long enough for the filings to settle. This would permit filming. The movie would show the formation of the iron filings into the expected lines-of-force pattern. Since neither the bar magnet nor chamber would be subject to gravity, both would remain in place, of course, with Christa's assistance.

Based on these considerations, place a white sheet on paper flat on a table. Sprinkle iron filings liberally onto the paper. Next center one of the bar magnet on the paper. Observe the formation of the lines of force. Take a photo of the pattern with a digital camera. Place the other bar magnet on the paper at different orientations with respect to the first magnet. For each orientation, take a photo to display the resulting lines-of-force pattern.

Graphing Lines of Force

The above demonstration can be done, in part, without the clutter of iron filings by using a small compass and a printed picture of the above lines-of-force photo. Enlarge the picture so that the bar magnet can be superimposed on the image in the photo. Starting near the north pole of the bar magnet, slide the compass along one of the lines-of-force in the photo. Watch the direction the compass needle points. Could this information be used to plot a graph of the curve of the lines of force formed by the iron filings under the influence of the bar magnet?

Design and Construction of a *Challenger* Bar Magnet Lines-of-Force Chamber

(For extra credit): Obtain a large rectangular sealable sandwich bag about the size of a sheet of unlined 3-ring note book paper. Fill it with iron filings and attempt the same experiments as described above. You might alter the design of the zip-lock magnetic bag chamber with a balsa-wood frame work to enhance viewing of the lines-of-force patterns.

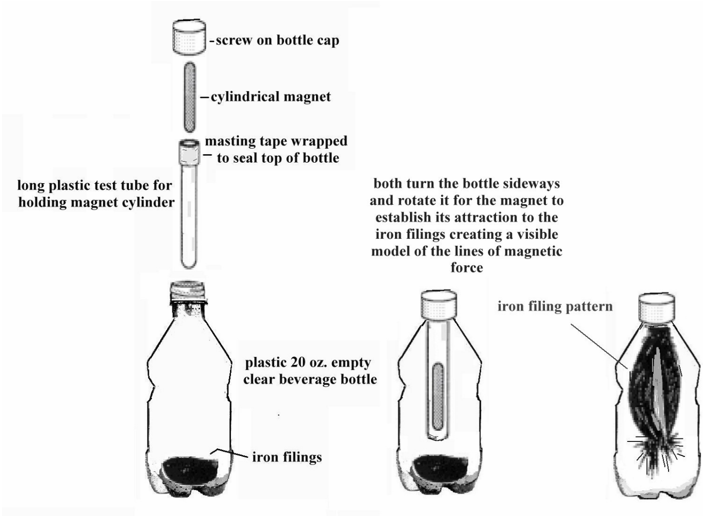
The Magnetic Electro-magnet Chamber Demonstration

There is an excellent classroom science experiment which closely replicates what Christa might have observed in the magnetic chamber during her *Challenger* mission. Rather than a cubicle chamber, the demonstration employs a clear plastic liter soda bottle. Because the magnet can be oriented parallel with the pull of gravity, the lines-of-force pattern formed by a strong magnetic force nulls out gravity's influence. This results in what would have been the pattern observed three dimensionally in the lost magnetic lesson chamber during January of 1986.

Perform the following procedure referring to the diagrams. First soak the bottle to remove the label. Next, fill your magnetic chamber (the bottle) about a fifth full of iron filings. Wrap enough masking tape around the top of the test tube so that it can be snugly inserted into the bottle's mouth so that the top opening is sealed. This keeps the iron filings from leaking out. Now insert the tube into the mouth of the bottle.

Next insert the cylindrical magnet into the plastic test tube. Then, replace the bottle cap on the bottle. Just as Christa proposed for her experiment in space, turn the bottle on its side and rotate it. Observe and record what happens to the iron filings. (The video recording is invaluable for later analysis and discussion.) Just as the zero-G magnetic chamber should have demonstrated the formation of a three-dimensional magnetic field, so will a three-dimensional pattern be formed tracing out the magnet's lines-of-force.

It would be good to carefully observe what happens to the iron filings at the magnet's end. They appear to project outward as though they are the edge bristles of a much used hair brush. Withdraw the magnet from the test tube. What happens to the iron filings?



What Happened?

(Study the video tape)

From the discussion of the science of magnetism, we have learned that individual atoms, in a magnetic material like iron, act as tiny magnets with north and south poles. Initially, because the atoms are organized in random orientations, they cancel one another and the iron is not magnetic, However, when a magnet is brought close to a piece of iron comprised of the individual atoms, those iron-atom magnets align with the nearby magnetic field. Therefore, the north poles of the iron atoms point in the same direction. The lining up makes the iron magnetic. It is attracted to the magnetic field brought near it.

With the cylindrical magnetic piece of iron inserted in the test tube, the atoms line up with the north poles facing one end of the rod and the south poles of the atoms facing the opposite end. Like the test tube magnet, the iron filings are also rod-shaped, so that each filing has its atoms lined up pointing along the length of the test tube magnetic rod.

The field of the cylindrical magnet projects from the end of the magnet and loops around the iron cylinder's side. The causes the iron filings to stick out like hair brush bristles on the ends of the magnet though they lie flat against the side of the magnetic cylinder. The overall shape of the filings combine to show approximately the shape of the magnetic field's lines of force in three dimensions.

Hopefully, this shape would have been similar to that of Christa's magnetic chamber. The lost lesson's iron-like filings would have clustered about the chamber's electro-magnet in like fashion.

Discussion: Bob Mayfield's discussion of magnetic filing behavior in zero-G versus one-G seems sound. However, watching the KC-135 video shows the filings behaving in a fashion that might compromise the on-orbit experiment. Performing the classroom magnetic experiment helps to understand difficulties that might have been encountered by Christa. Since the force of the electromagnet is quite weak, and the filings would be randomly dispersed about the clear chamber, would the drawing power be sufficient to pull the metal filings into a lines-of-force pattern, even in zero-G? Perhaps, Christa would have had to move the chamber back and force to assist the collection of the particles about the center electro-magnet, assisting the drawing power of the field in capturing the filings.

Finally: Christa performed the magnetism demonstration both without gravity, on the KC-135 zero G aircraft, and in the shuttle mock-up at the Johnson Space Center. Carefully view both videos. What, if anything, is alike and what is different about the two times the experiment was practiced? Click on the videos below for your evaluation. (Since the experiment was only designed to work in orbit, i.e., with zero gravity, neither the ground nor KC-135 practice trials actuated the electro-magnet. However, the KC-135 trial did have the file-like particles in the magnetism chamber.)

What deserves consideration and investigation were the proposed ways Christa suggested moving the magnetic chamber during the course of the experiment. List Christa's suggestions.

How do you believe Christa's suggestions would benefit the performance of the experiment? (The discussion above suggests the answer.)

Hold down CTRL Key and click on:
magnetism_chamber_ground_demonstration.wmv
The video is played in Media Player

magnetic_chamber_zero_G_practice.wmv

For Additional Study

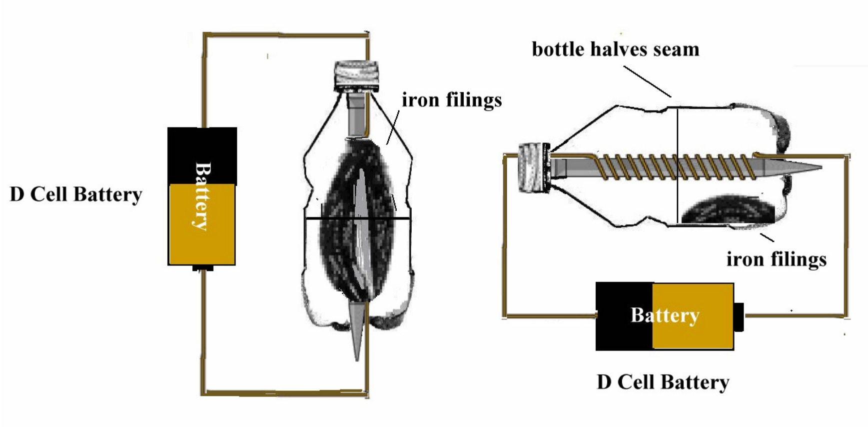
The Electromagnetic Chamber Demonstration

The experiment featured above can be readily performed using an iron magnet, but Christa's lost magnetic lesson employed an electro-magnet. For those wanting a more ambitious investigation with an experiment more closely replicating that proposed for Christa, the following demonstration is offered:

To begin, carefully examine the above videos to grasp an understanding of how the magnetic chamber was designed. Note that the electromagnet axially passes through the enclosed volume. Of course, in zero-g, the iron filings must be held within the chamber, otherwise, they might be inhaled by the crew. Though the zero-g practice used the inflated chamber, obviously, electrical current was not applied. The iron filings do not appear to cling to the centered iron rod whatsoever. In fact, they randomly sail about the enclosure, or, act together as an inertial mass responding to the motion imparted to the chamber by Christa and others. (*Watching the above videos explains exactly why there is no clinging of filings to the electromagnet. The ground demonstration includes the battery pack for the electromagnet. The zero-g practice does not.*)

The nature of zero-g KC-135 practices allows less than a half minute per parabolic gravity-less maneuver. While this might have been sufficient to observe the lines-of-force pattern, the jostling of the apparatus would have made success problematical. However, on orbit, Christa would not face such a handicap. Plenty of time would be available to establish the effect of the electromagnet's lines of force on the iron filings. (*In the video Christa speaks of having two and one half minutes to orient the chamber in various attitudes to examine the pattern the iron filings assume with the application of electro-magnetism. She suggests examining on film what happens if she releases the chamber to "free-flow" across the Challenger's cabin. Indeed, Christa is making a significant scientific contribution to the Magnetic Lost Lesson demonstration. This would be much like the previous experiment. The soda bottle chamber was turned over and rotated so that the magnetic field could draw the iron filings into* *the final lines of force pattern.*)

Actually, the previous experiment offers an easy way of replicating the proposed *Challenger* electro-magnet lesson. By simply center boring a hole in the bottom of the soda bottle with an ice pick, an enclosed chamber can be fashioned to house the axial electromagnet iron cylinder. The figure below illustrates modifications to the bottle apparatus in order to replicate the electro-magnet lost lesson chamber demonstration in the classroom.



Materials:

1. D Cell Battery
2. six inch nail or iron bar
3. clear plastic empty soda bottle (20 ounze)
4. 22 gauge insulated copper wire
5. iron filings
6. scissors for cutting bottle in two
7. clear adhesive tape for sealing bottle
8. wire cutters

Note: What remains unchanged from the previous magnetic soda bottle chamber experiment is the orientation of the final set-up. The electromagnet is also oriented perpendicular to the earth. This nulls out the presence of gravity perpendicular to the length of the magnet so that, as before, the filings will assume a symmetrical pattern. Of course, gravity remains to sort of "squash" the three dimensional pattern toward the bottle's base. Likewise, unchanged are most of the materials. Only the permanent magnet is replaced. Its counterpart, an electro-magnet, is an iron rod of similar diameter but much longer. About the iron rod is wound insulated electrical wire, looped in windings so that electrical current can be applied via a battery and switch.

The electromagnet itself is centered in the chamber with only the center portion of the axial rod being magnetized. With a strong enough magnetic field, the three-dimensional pattern formed would extend considerably from the center of the chamber.

While the iron filings pattern formed is similar, missing is the pattern extending the free end of the permanent cylindrical magnet. The iron filing bristles extending beneath the test tube would not be present.

Procedure:

Constructing the altered chamber is a three phase process:

1) modifying the chamber soda bottle used in the previous experiment, 2) constructing the electro-magnet assembly, and 3) installing the electro-magnet assembly in the chamber.

Modifying the Soda Bottle: Because an ideal electromagnet core is an iron nail, the chamber needs adapting to the length of the longest readily purchased iron nail. Nails beyond a half foot in length are not easily found. For that reason, the height of the empty soda bottle needs reduction. This is readily done by cutting a four-six inch section out of the bottle's length. The remaining halves are readily reattached by taping around the seam joining the halves with clear adhesive tape. Winding the tape around the seam several times improves the strength of the attachment.

Because the electromagnet is "un-magnetized" without the application of the battery's current, the sealed capping process of the permanent magnet demonstration is not as critical. Without electricity, there is no magnetism so that the filings are free to rest anywhere within the bottle. (Note: While this is initially true, after several applications of electricity, the nail tends to become a weak permanent magnet.)

The assembly of the electro-magnet is rudimentary. Simply coil No. 22 gauge insulated copper wire around a six inch long iron nail. (Approximately 10 feet of wire is needed.) The copper wire windings should come within a half inch of the mouth of the bottle and, likewise, a half inch above the bottom opening. Leave several feet of wire extending beyond the top-most and bottom-most loops of the copper wire.

Installing the electromagnet assembly in the bottle chamber is done through either of two ways. (Note: The first approach requires infilling with iron filings prior to inserting the electromagnet assembly.) Thread one of the extended wire leads through the bottle's mouth then through the axial hole in the bottle's bottom. By pulling the bottom wire, the electromagnet rod is drawn through the bottle's mouth as well as the bottom hole. The height of the bottle should have been earlier altered so that the unwound portions of the iron nail protrude through the top and bottom bottle openings. Use masking tape looped around the top of the iron nail to snugly fit it into the bottle's mouth. The bottom hole should be snug enough by virtue of penetrating it with the nail's pointed end. (Note: Be careful not to fray the wire insulation when piecing/enlarging the bottom hole.)

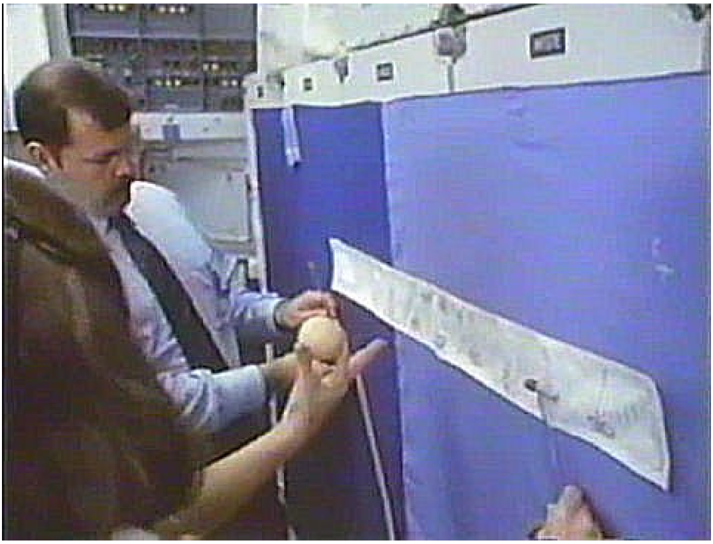
The second approach for installing the electromagnet assembly deals with the bottle's unattached top and bottom halves. First, thread the nail's pointed end wire through the mouth of the top half of the bottle. (Pour an adequate quantity of iron filings into the bottom half of the bottle orienting that half so that filings do no escape the small hole in the bottom.) Next, thread the wire through the bottom hole of the bottle's bottom half. Push the pointed end of the nail through the bottom hole being careful not to fray the copper wire's insulation or allow iron filings to escape. Bring the halves of the bottle together to form an attachment seam. The top unwound half inch of the nail should protrude through the top opening. Wrap clear adhesive tape around the seam several times to secure the two halves in place so that iron filing cannot escape through the seam. Of course, as before snug the top attachment with masking tape. (Note: Of the two approaches, the first is probably the easier to perform.)

Attach a "D" battery to the circuit by pressing, or taping, one of the wires to the battery's anode (positive terminal) and the other wire to the cathode (negative terminal.) At once, the iron nail becomes magnetic. As with the previous experiment roll the chamber over and move it so that the electromagnets lines of force can be established. Finally, orient the chamber bottle vertically with the earth.

Supplemental Information

An excellent video produced by the NASA Langley Research Center deals with both making an electro-magnet and experimenting with it. After depressing the ctrl key, click here to view the one minute video.

THE LOST NEWTON'S LAWS LESSON



"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.

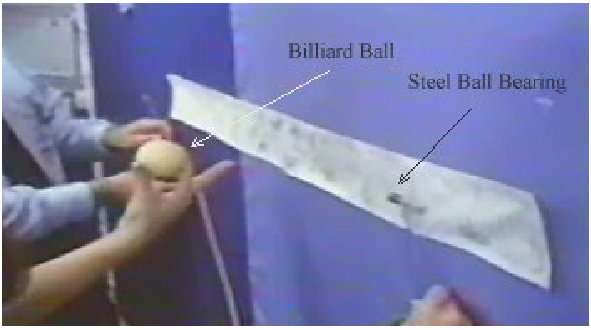
Background:

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 (=)equals (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



Hold down CTRL Key and click on:
newton_experiment_ground_practice.wmv

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: (A)cceleration (=) equals (F)orce (/) Divided by (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
Hold down CTRL Key and click on:
newtons_laws_zeroG.wmv

A Classroom Version of Christa's Newton's Laws Lost Lesson

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

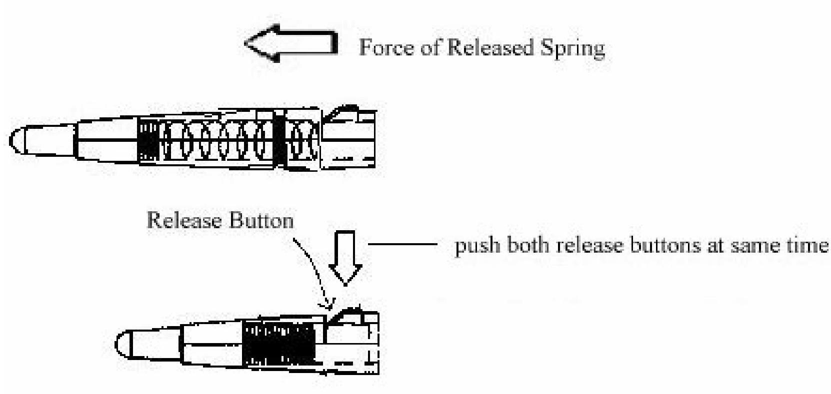
Background:

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 about 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?

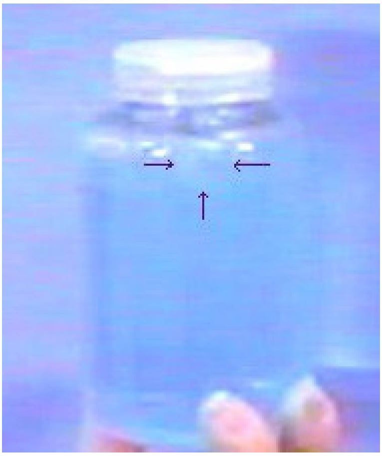
4. How would you suggest changing the proposed experiment to assure a more likely successful outcome?

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.

THE LOST EFFERVESCENCE LESSON

The Mystery of Christa's Big Bubble



"See the bubbles…the big one…I love it."

Background Science Summary:

Effervescence, i.e., the presence of bubbles in a liquid, can be produced both by a chemical reaction and physical phenomena. The chemical compound contained in an Alka-Selzer® tablet produces effervescence through a chemical reaction. The tablet with its chemical formula, $NaHCO_3$, is also known as "baking soda" or sodium bicarbonate. When dissolved in water, the chemical reaction occurs. It results in the tablet producing, as a byproduct, a gas known as carbon dioxide with the symbol, CO_2 .

Of course, effervescence can be produced in water by simply blowing carbon dioxide gas into the liquid, pressurizing it. No chemical reaction is involved. However, the pressure of the gas within can be affected through physical means (shaking).

Hypothesis:

The size of carbon dioxide bubbles formed by the effervescent chemical reaction is affected by the scale (size) of the Alka-Selzer® granules as well as the physical shaking of the contents.

Materials:

1. Alka-Selzer tablet bottle
2. Plastic safety goggles
3. Roll of paper towels for cleanup
4. Empty peanut butter jar and screw on lid
5. Half gallon of tap water in plastic container
6. Watch with second hand
7. Tablespoon and teaspoon for crushing tablet
8. Ruler
9. (Optional) Video Camcorder with flip out playback screen

Procedure:

(Optional: Have an assistant video tape the procedure just as Christa was video taped.)

Deposit an Alka-Selzer® tablet in the water bottle. After the tablet dissolves in the clear jar, observe the size and number of bubbles within the water. Shake the jar vigorously. Do the number of bubbles increase? Does the size of the bubbles increase. What do you think causes the increase in pressure as a result of the shaking? How does the shaking contribute to bubble size and quantity? What is going on with the bubbles in the closed jar?

What Happened?

(Study the video tape by clicking below.)

The chemical reaction began when the sodium bicarbonate tablet mixed with water. The chemical reaction released carbon dioxide. The gas was contained in the bubbles seen in the water. Alka-Selzer® tablets are known as an antacid or "base". An antacid is the opposite of what is called an "acid". A base's purpose is to weaken (neutralize) acid levels in the stomach. Obviously, acid in contact with the stomach's lining causes discomfort. As such, the tablet provides relief from indigestion and "heartburn."

While it is true that the carbon dioxide gas was produced by the chemical reaction, what about a non-chemical or physical change causing the pressure and size of the carbon dioxide bubbles to increase? For example, have you ever shaken a bottle or can of a carbonated beverage then opened it. The shaking increases the pressure of the gas within the vessel. When opened, the liquid beverage spews out with the over-pressurized carbon dioxide gas. Obviously, only the shaking can be blamed for the increase in gas pressure. Was the chemical reaction responsible for the bubble's size?

(Carefully view the following video for the explanation voiced by Bob Mayfield.) And, additionally, what effect did having no gravity contribute to the bubble's size?

Discussion: Why did one of the bubbles produced by the CO2 gas become so much larger than the others? A major clue is revealed by the video of the capsule dissolving in the water. See if you are able to replicate the formation of the large bubble based on the explanation voiced in the video.

Finally: Christa performed the effervescence demonstration both without gravity, on the KC-135 zero G aircraft, and in the shuttle mock-up area of the Johnson Space Center. Carefully view both videos. What, if anything, is alike and what is different about the two times the experiment was conducted? Click on the video panels below for your assessment.

Based on your findings, if you had an upset stomach, would you rather ingest an Alka-Selzer® tablet in space or on the ground. Discuss the reasons for your answer based on comparing how the tablet dissolved in zero-G and one-G.

Effervescence in Zero G
Hold down CTRL Key and click on:
effervescence_zero_G.wmv
The video is played in Media Player

Efferescence in One G
Hold down CRTL Key and click on:
effervescence_in_one_G.wmv
The video is played in Media Player

THE LOST CHROMATOGRAPHY LESSON

“Let me take the glass off?”

Background Science Summary:

The wonder of the chromatography experiment, whether on earth or in the zero-G heavens, is the capillary action of water movement in the filter paper strip. Defying both the force of gravity and the expected inertia of the water drop, the liquid advances toward the ink spot. Were it not for an understanding of capillary action, the gradual soaking toward the ink spot would be a mystery. Indeed, what is the process which separates various colors of ink from the ink spot?

How it works: Though ink appears to be composed of one color, it is not. Actually, several colored *pigments* blend together to make the color. This is known as a *mixture*. Artists *mix* different paint colors, like red, blue and green, to achieve a desired color which is a combination of the three basic colors. Because of chromatography, ink becomes soaked in the water drop so that the different pigments begin to separate or "bleed" apart. This results in the true colors being discovered. For Christa, one of the true colors in the black ink spot separated out by chromatography was blue.

But more discussion of the science is needed. Why does one ink separate apart from another, and why does the water move toward the ink spot in the filter paper strip? The first question's answer is: When a substance dissolves in a liquid like water, it is said to be soluble. Since this quality of being soluble differs in substances, each color will dissolve at a different rate so ink color separation occurs as the water soaks into the black ink spot. While that explains the separation, what about the creeping movement of the water toward the ink spot?

One definition of capillary action is: The action (some call it *wicking*) whereby a liquid like water spontaneously slowly moves up thin tubes and/or fibers as a result of forces, adhesive and cohesive, as well as surface tension. While this is a definition of the phenomena, what actually causes it? The answer is altogether complicated such that scientists have studied the process for centuries. Yet, without it mankind would be in severe difficulties for survival. Plants grow as a result of the process of capillary action providing food for life. Suffice it to say that capillary action consists of having various forces contributing to the adhesion of water or another liquid to a solid such as wood as well as the <u>cohesion</u> of water or other liquid molecules with one another playing a critical role in the climbing or moving process.

Christa Planning Chromatography in Space Demonstration

Hold down CTRL Key and click on:
chromatography_ground_practice.wmv
The video is played in media player.

In the above video, Christa deals with planning the application of the water via the dropper to the chromatography test paper. She considers camera angles in order to record the capillary/osmosis process in zero-G as the water ascends toward the ink spot. The team discusses how launch and on-orbit operations may affect the stowed test paper strip prior to performing the experiment.

The photo below is cropped from Christa's ground exercise of the chromatography experiment video.

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Classroom Version of Chromatography Lost Lesson

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

Background:

A simple technique is used to separate colored ink pigments from black ink. Being soluble, the ink will dissolve in water and the mixture or solution will then be absorbed on filter paper. As the dissolved solvent rises on the paper and evaporates, it leaves a trail of colors on its path.

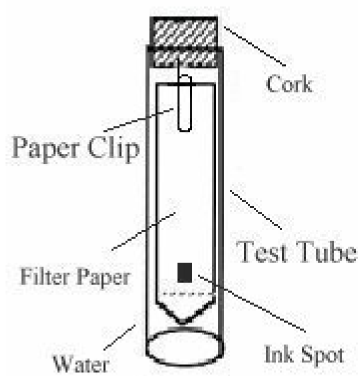


Figure 1.
Christa's Lost
Chromatography Lesson

Materials:

1. Ordinary filter paper or paper towel (about a half inch by six inches)
2. Black felt-tip pens
3. Test tube(s)
4. Test tube holder (rack)
5. Paper clip(s)
6. Cork(s) which fit the mouth of the test tube(s)

Process:

* Cut the filter paper into a strip so that fits within the test tube. Next, cut the lower end of the paper strip so that it points toward the bottom of the test tube. (see drawing above right) Draw a light pencil line across the paper strip where the point begins. Bend open a paper clip and stick one end into the cork test tube stopper. Slide the paper strip into the clip in order to hang the strip into the test tube. Watch the video

of Christa to see how her apparatus was constructed. Note in the video that the sides of the strip should not touch the glass.

*Just as Christa's filter strip has a black ink spot with a black felt-tip pen, likewise, place a small ink dot on the center of the pencil line.

*Rather than applying a drop of water with a dropper as did Christa, add enough water to the test tube to cover the bottom of the filter paper but not enough to reach the ink dot. (Note the video audio commentary by Christa about where the water should be applied to the strip of filter paper.)

*Next, place the filter paper in the test tube with the dot above the water level just as Christa did in the video.

*Watch what happens compared to what is seen in Christa's video.

*While the video shows the water only barely going up the filter paper above the dot, for this experiment let the water go up the filter paper within an inch of the top, then remove the strip and let it dry.

*Are there color spots at different lengths above the original start point? Try the experiment again with a different pen. What do you see?

Analysis:

Because the ink was water-soluble, it dissolved into the filter paper. As the ink moved up because of capillary action on the paper, the various pigment colors were deposited based both on their solubility in water as well as their attraction to the paper. It is seen that the more soluble the ink color, the higher the molecules in the pigment ascended up the paper.

Questions to Answer:

1. What color(s) separated from Christa's black ink? What color(s) separated from the above experiment? Explain the difference in your own words.

2. How might the separation of ink colors be used to solve a crime?

What Would Have Happened on Challenger?

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

1. How would the absence of gravity have affected the apparatus designed for the classroom?
2. Would the experiment have been more difficult to perform without gravity? Why or why not?
3. Could Christa have performed the experiment in orbit as it was in the classroom, i.e., with the water in the bottom of the test tube? Why do you think Christa's experiment used an eye dropper to apply the water solution?
4. Could the chromatography experiment have been combined with the lost hydroponics lesson apparatus for the on-orbit demonstration by Christa? Why or why not? How might you have designed an added chamber for the chromatography demonstration?

THE LOST SIMPLE MACHINES LESSON

Introduction:

Among the six lost lessons, the simple machines demonstration was most rudimentary. Perhaps, it is because most earth-based simple machines are crafted to overcome the handicap of gravity. In space, without the effect of gravity, no difficulty in pushing, pulling, lifting, or rotating the most massive articles is encountered. However, there remain significant uses for simple machines, even in space. The challenge of the simple machines lost lesson was to demonstrate how they might be used in a zero-g space environment. Even without gravity, the principles of Newton's action/reaction laws call for simple machines to accommodate certain activities. For example, astronauts had exercised on stationary pedal type bikes during the Skylab Programs. Though the bike wheel did not transport the user on a path about the lab's interior, there was the mechanical advantage of pedal-leverage rotating the wheel. By applying resistance via a braking mechanism, the amount of effort (work) the astronaut performed in exercising could be adjusted. Indeed, even in space, simple machines of all types are employed.

Mayfield's summary paragraph for the simple machines lesson described an elemental collection of stowed equipment. The demonstration apparatus included an aluminum inclined plane (10” long by 2” wide by 3” high), a screw driver with a screw insert, a small four wheeled cart the width of the included plane, and a pulley. Unfortunately, among the video clips reviewed during the ground and zero-g practices, none depicted the lost simple machines lesson. For that reason, this editor has injected a degree of speculation into how the lost simple machines lesson might have been executed. Nevertheless, Mayfield’s descriptions are helpful so that these interpretations do adhere to what was intended to teach the principles described.

Background:

Before continuing, read carefully Bob Mayfield’s discussion of the proposed simple machines experiment. How the demonstration evolved is, in itself, a useful learning experience teaching the principles of simple machines. The culmination of the iterative process was an inclined plane, screw, wheeled cart, and pulley experiment. Obviously, no benefit results from rolling a cart up an inline plane with gravity absent. However, the use of a screw driver, whether on earth or in orbit, offers the ability to overcome friction between screw threads and the penetrated material. Likewise, the inclined plane, though useless as a lifting assist, has benefits as a wedge in separating surfaces held together by adhesive, pressure or other means.

As Mayfield elaborates, the challenge in a space environment is understanding the application of simple machines in zero-gravity. He suggests the pulley as an example. The device provides a mechanical advantage which is directional. Should a solar panel or other mechanism malfunction in a binding fashion, the mechanical advantage applied by a pulley would be advantageous. The force an astronaut could apply by simply grabbing and pulling the “stuck” structure might not be sufficient.

Likewise, even though rolling the cart up the aluminum inclined plane has no merit, using *wheel-like* ball bearings to overcome fiction in a whirling centrifuge has advantages. The space station actually has a trolley type apparatus whose wheel-like transportation caddy applies the advantage of the simple machine known as the wheel. Again, simple machines overcome the resistance of sliding friction even in the weightlessness of space.

A Classroom Version of Christa's Simple Machines Lost Lesson

The following demonstration replicates Christa's experiment:

Principles:

Explain to the class that there are six simple machines and list them: lever, wheel and axle, screw, inclined plane, wedge, and the pulley. The purpose of a simple machine is to make it easier to do work. Whether work is mowing the law or digging dirt, the tools used are a combination of the six basic simple machines listed above. Perhaps, the class has reached a math maturity to understand that work is defined as applying a force through a distance. If that is so, explain that work is equal to the applied force times the distance the force is applied through.

To help the students grasp the concept, a simple means is imagining that a given job takes a given amount of work. Since the amount of work is the product of force applied for a given distance, it is logical that increasing the distance diminishes the force needed to do the same amount of work. For example, a weaker student, not able to apply much force to an object, is able to do the same amount of work as a strong student by using a simple machine. The machine allows the student to apply a reduced force over an increased distance, even though the forces applied by the students move the object the same distance.

Though mysterious, it is defined by the term *mechanical advantage*. This is the concept that explains the advantage of simple machines: increasing the applied distance of a reduced force to obtain the same result in work done. The ratio of the distance a force is indirectly applied to an object of mass to directly moving the object is known as the mechanical advantage of a simple or compound machine. Simply put: *mechanical advantage is the exchange of force for distance.*

Again, an example is helpful. Lifting a one pound weight vertically without the help of a machine indicates a mechanical advantage of one, i.e., nothing is gained to help lift the weight However, if one pushes that same block up an inclined plane (a ramp) which reaches the same height as lifting the weight vertically, the force needed is proportionally less based on the length of the incline. If a one pound weight is lifted vertically one foot, it would require a pound of force to move the weight one foot. A "foot-pound" of work is done..

Using a ramp (inclined plane) which is two foot long and a foot tall requires approximately half as much force to reach the one foot elevation. This is true even though the weight moved two feet instead of one foot vertically. Mathematically, a half pound of force was applied for two feet. Therefore, .5 pounds of applied force times two feet amounts to a foot pound of work. Equal amounts of work are done in both cases even though the second case required half the force. The mechanical advantage of the ramp is two.

Of course, the force needed to overcome the resisting friction of the weight sliding against the ramp surface has been ignored. If taken into account for the ramp, greater work would have been required than a foot pound. The example gives the ideal mechanical advantage not the actual mechanical advantage. Such is the case when losses are ignored from friction, air resistance and other forces.

Materials:

1) An inclined block of wood, 2" wide by 3" high with a 10" long incline (cut from a building framing wood stud) or simply use a board as seen below with one end propped on the edge of a chair

2) A matchbook car with less than a two inch wheelbase.

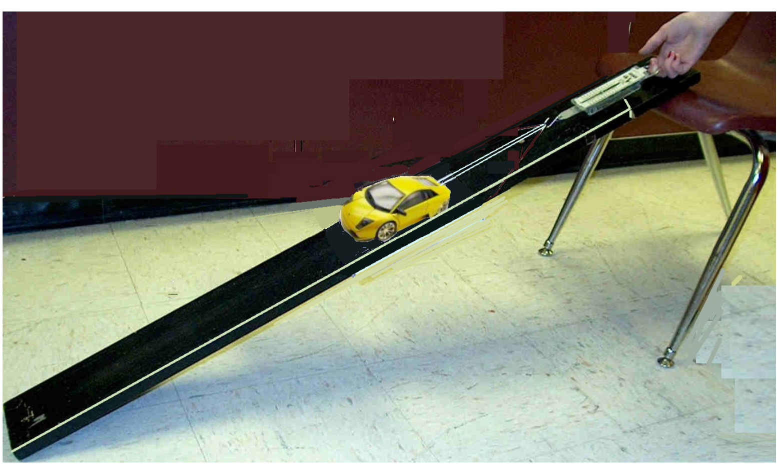
3) A screwdriver and wood screws.

4) A hammer and nail

5) A pair of pulleys.

6) cord

7) A spring scale to measure weight or applied force.



Process of Experiments:

*1. Collect the materials listed above. (See above photos.) Attach the spring scale hook to the toy car and slowly pull the car up the inclined plane noting the indicated force measured by the spring scale. Multiply the force in pounds by the length of the ramp in feet to determine the work done. What is the mechanical advantage of the inclined plane?

*2. Attach the spring scale via its hook to the toy car. (See pictures below.) Attach the other end of the scale to a short length of the cord. Thread the rope through the pulley. Hold the pulley hook above the floor. Pull the cord slowly and steadily so that the car is elevated vertically above the floor a given height. Record the spring force while lifting the car. What is the mechanical advantage of the pulley? What was the advantage of using the pulley? Add a second pulley to the apparatus as shown below. Again, pull the cord elevating the car a given height above the floor. Observe the reading on the spring scale as the cord is slowly and steadily pulled.

*3. Hammer a nail lightly into the wood ramp to make a "starter hole" for a screw. After removing the nail, place the pointed end of a screw into the starter hole and begin screwing the screw into the board with the screwdriver. Note how difficult it is to turn the screw driver. Remove the screw and repeat the process with a screw with twice as many threads per inch. Notice how much easier it is to turn the screw driver, but how much more slowly the screw penetrates the board. Explain the difference in turning force and penetration

progress. The explanation is that the screw threads are, in effect, inclined planes of different lengths wrapped around the circumference of each of the screws. Because one is longer than the other, the force required is less.

Compare the mechanical advantage of the two screws.

Analysis:

The most useful concept learned from performing the lost simple machines experiments is the concept of work as a product of applying a constant force over a prescribed distance. Understanding the benefit of simple machines to all mankind comes from grasping this principle. Each application of a simple machine should address the concept. Even though the single pulley provides no mechanical advantage, the ability to redirect the application of force is significant. However, a second pulley should be added to demonstrate the mechanical advantage of a pulley system.

Questions to Answer:

1. What was the ratio of the force divided by the distance the car moved up the incline in the first experiment? How much work was accomplished in foot pounds in route to the final elevation? How much work was done when the car was lifted vertically to the same height about floor? What was the ratio of the force needed to pull the car up the ramp to the force needed to lift the car vertically to the same elevation? What is the mechanical advantage of the inclined plane?

2. In the second experiment using a single pulley, how much force was required to lift the car three feet above the floor? Repeat the lifting of the car pulling the cord in a different direction while recording the force required to lift the car to the same height above the floor. Did the direction in which the cord was pulled make any difference when the car was lifted a second time?

3. When a second pulley was added to the apparatus shown for the second experiment, what was the force required to lift the car three foot off the floor using the pair of pulleys? How far did the rope have to be pulled to lift the car three feet off the floor compared to the distance the rope had to be pulled with a single pulley to lift the car three feet? What was the ratio of the forces between the single pulley lifting of the car and the double pulley lifting? What is the mechanical advantage of the two pulley apparatus? What are the two ways to calculate the mechanical advantage?

4. After comparing the force needed to screw each of the two screws in the third experiment, think of a way that the mechanical advantage of the screws might be calculated. Besides the threads being inclined planes surrounding each screw, what other simple machine is suggested which assists in cutting into the wood fibers? How might friction be reduced so that less force is needed to turn the screwdriver?

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 the simple machines experiment 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?

THE ULTIMATE FIELD TRIP
Challengers' First Lost Live Lesson

Christa's name for her mission:
THE ULTIMATE FIELD TRIP

Introduction:

Besides the six lost science lessons scheduled for filming aboard *Challenger*, two televised "live lessons" were planned for the sixth day of the mission. The time scheduled for each was fifteen minutes. These were to be aired on the Public Broadcasting Network (PBS) at 10:40 a.m. and 10:40 p.m. Central Standard Time.

The first lesson (actually given its name by Christa) was "The Ultimate Field Trip". It dealt with explaining and describing to students the general layout of the shuttle. Additionally, crewmembers (Commander Dick Scobee, Pilot Mike Smith and others) would be introduced. Click on the hyperlink Ultimate Field Trip to view Christa's practice session. The NASA video archives contained a wonderful clip of Christa actually "walking through" a practice run of both live lessons. (Click on the hyperlink "walking through" to view the set up for the practice sessions of the two live lessons. The second live lesson is addressed in some detail in Bob Mayfield's paper. It was entitled "Where We've Been, Where We've Going."

Background:

The background description for the first live lesson, "The Ultimate Field Trip" comes from the NASA publication "Teacher in Space Project." It is stated below:

"This lesson is based on a quotation by Teacher in Space Christa McAuliffe who described her opportunity to go into space as 'the ultimate field trip.'

Viewer Objectives:

1. To observe the major areas of the Shuttle and describe their function
2. To list and describe the major kinds of activities crewmembers perform aboard the Shuttle
3. To compare and contrast daily activities in microgravity with those on Earth.

Video Lesson Description:

This lesson from space will begin in the flight deck area of the Challenger where Christa McAuliffe will introduce the commander and pilot and will point out the Shuttle controls, computers, and payload bay.

When she arrives at the mid-deck, McAuliffe will show viewers the kinds of equipment and processes which help human beings live comfortably and safely in the microgravity environment of the Shuttle.

* * * * * * *

Discussion:

After reading the above scenario, watch the video once more, starting with the setup planning by Christa, Barbara Morgan, and Astronaut Mike Smith. Note the camera is mounted on a tripod. Of course, except for stabilizing the camera, the tripod is an apparatus not needed in orbit where gravity is not a factor. The camera, unlike that to be used for the six lost lessons, is a video type, not film. This would permit broadcast through the Public Broadcasting System, an educational television network seen throughout the United States.

Christa's trial practice begins in the flight deck area where Commander Dick Scobee and Pilot Michael Smith (actually present for the practice) are introduced. After describing some items such as the onboard computer, Christa descends into the mid-deck area. There, she describes the WMS (Waste Management System - the toilet), the privacy curtain, the use of the sleep restraint, and the galley for food preparation. Also, she demonstrates use of the drawer-like storage lockers. Specifically, she explains the need for tie down restraints to keep stowed items from floating away.

A Classroom Version of Christa's "Ultimate Field Trip" Lost Lesson

The following demonstration replicates Christa's experiment:

Principles:

As a tour, a classroom version would include reports by students assigned the topics addressed in the above description of Christa's shuttle walk-through.

Materials:

NASA documents found in the school or local public library. CDROMs such as the NASA *Space Educators' Handbook*.

The “The Ultimate Field Trip” in the Classroom:

*1. Assign different students a research project on: 1. How astronauts sleep on the Shuttle 2. How astronauts use the waste management system on the Shuttle 3. How astronauts use the onboard personal computer on the Shuttle 4. How astronauts prepare meals on the Shuttle 5. How astronauts bath and dress on the Shuttle 6. How astronauts pilot the Shuttle 7. How astronauts use the cargo bay’s robotic arm on the Shuttle 8. How astronauts entertain themselves apart from official duties on the Shuttle, and other Shuttle activities which can be assigned members of the class.

*2. Have each student write a one page report for oral presentation to the class. Let each student pretend he or she is a Shuttle astronaut teaching from space. Additionally, assign a student as the mission control center *capcom* who will introduce the individual reports and student speakers.

*3. Suggest to the remaining students that they imagine the presenters as onboard the Shuttle presenting the same kind of information Christa intended to broadcast during her *Ultimate Field Trip* lesson.

*4. Using the biographical backgrounds of each of the Challenger Seven crew members, assign individual students the role of introducing the crew to the class. Let the student assigned the capcom role introduce Christa. Assign a student Christa’s role of introducing Commander Richard Scobee followed by another student introducing Pilot Mike Smith and so on until all seven crew members have been introduced to the class. (NASA and many other web pages feature biographies of each crew member.)

*5. Ask each student to consider demonstrating a walk through of the school. What would be important to show a new student about rooms assigned for: lunch, science experiments, and other locations needed to get through a day at school?

Analysis:

1. The role playing exercise offers unique learning opportunities. One who presents also learns the topic more fully than one who is taught. Each student who is assigned a topic becomes the topic's expert. Whether the subject is the Space Shuttle or the life of a member of the *Challenger* crew, the assigned student is the "go-to-person" for information.

2. Christa was not a science teacher though she, certainly, had previous course work in the sciences. Yet, she became quite expert in conducting the lost science lessons in innovated ways. This is evidence that a gifted teacher is very adaptable. Additionally, and, perhaps, most importantly, an excellent teacher is likewise an outstanding student. Christa McAuliffe was both.

Questions to Answer:

1. What difficulties might Christa have faced that a teacher in a school class room would not have faced?
2. What benefits did Christa have in teaching onboard an orbiting spaceship compared to an earth based classroom?
3. How would you have planned the lesson as far as using some kind of "black-board", a video camera, and "show-and-tell" models?

What Would Have Happened on Challenger?

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

1. What added handicap exists on the Challenger, not present for the classroom activity?
2. If Christa had accidentally released a "show and tell" item, what might have happened?
3. Why was using a blackboard and chalk discouraged?

4. If you were to teach the seven member astronaut crew a lesson onboard the shuttle, how would you organize the shuttle into a classroom based on Christa's description of the shuttle interior?
5. How long would a class period be and why?

WHERE WE'VE BEEN AND WHERE WE'RE GOING, WHY?
Challenger's Second Lost Live Lesson

"Marshmallows…otherwise known as cotton balls and *(candy)* beans!"
Where We've Been and Where We're Going, Why?
Challenger's Second Live Lesson

Introduction:

Besides the six lost science lessons scheduled for filming aboard *Challenger*, two televised "live lessons" were planned for the sixth day of the mission. The time scheduled for each was fifteen minutes. These were to be aired on the Public Broadcasting Network (PBS) at 10:40 a.m. and 10:40 p.m. Central Standard Time.

Unlike, the first live lesson which was a simple tour of the Shuttle, the second is much like the filmed six lost lessons. However, only fifteen minutes time was planned for its execution.

The second live lesson is addressed in some detail in Bob Mayfield's paper. It was entitled "Where We've Been, Where We've Going, Why?." Reading the planned choreography of various mixing demonstrations shows the challenge Christa faced. Remembering that Christa was expected to narrate each demonstration impresses all with Christa's demeanor. Throughout the practice video, she appears cheerful, dedicated and fully in command of what was expected of her. This she did despite knowing that millions of students, young and old, would be attending her class on day 6 of the mission.

Background:

The background description for the second live lesson, "Where We've Been and Where We're Going Why? " comes from the NASA publication: "Teacher in Space Project:"

Where We've Been, Where We're Going, Why?
Viewer Objectives:

1. To explain some advantages and disadvantages of manufacturing in a microgravity environment
2. To describe spinoffs and other benefits which have evolved from the space program
3. To list ways in which the modular Space Station would change the lives of human beings

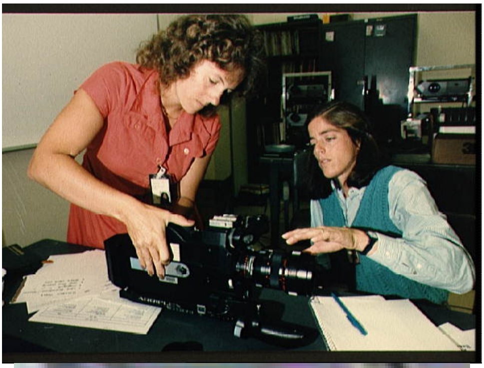
Video Lesson Description:

As the lesson from space begins, Christa McAuliffe will refer to the models of the Wright Brothers' plane and of a proposed NASA Space Station to help viewers recall that only 82 years separate that early flight and today's life in space.

McAuliffe will discuss the reasons we are living and working in space, covering astronomy, Earth observations, experiments onboard the Shuttle, satellites on- board the mission, materials processing, and technological advances.

Discussion:

After reading the above scenario, watch the video once more, starting with the set up planning video by Christa, Barbara Morgan, and Astronaut Mike Smith. Note the camera is mounted on a tripod. [This is a video camera, not the film camera to have been employed for the six lost lessons. The motion picture camera was called the Airiflex and is shown below being examined by Christa and Barbara. The video camera used in the ground practice is shown in the below right photo. While the film camera seems quite cumbersome compared to the video counterpart, in zero-g the Airiflex mass would be quite manageable.]



Concerning the tripod, Pilot Mike Smith talks in the video of "coming down from the flight deck to help set up the camera." This indicates the tripod would have been used as the camera's permanent mount for the live lesson, otherwise, it would have floated randomly about.

Because the live lesson camera, unlike that to be used for the six lost lessons, was a video type, it would have broadcast a television signal via the Public Broadcasting System, an educational television network seen throughout the United States.

Christa's second live lesson practice begins in the mid-deck area. In preparation for the scene, Christa asks Judy Resnik, who is controlling the camera, to zoom in for the best view of the scene. What Judy views is seen on her monitor displayed at the camera control station.

After some planning, the practice begins with the words, "Challenger, (This is)…Houston. We have good video. We're ready for your lesson. Go ahead Christa." And Christa begins with, "We've come a long way from the Wright Brothers' plane to the Shuttle." (Christa pretends to hold up a model of the Wright Brothers' plane for the TV camera then she brings an imaginary model of the space station in view.)

In order to more carefully analyze the second live lesson, a portion of Bob Mayfield's description is repeated below along with the editor's comments in brackets […].

"Several demonstrations will be conducted to illustrate the behavior of materials in microgravity. A sphere of orange juice will be formed carefully from a drink container. The fact that liquids form perfect spheres in space is useful in forming mono-disperse latex beads, for instance, which can be used by the Bureau of Standards. Mixing of molecules of different substances will be illustrated using marshmallows and chocolate candies in a plastic bag. [*This is what Christa is alluding to in the bag of cotton balls chosen to replicate the marshmallows.*]

Mixing of liquids of differing densities will be demonstrated using salad oil and colored water sealed in lexan bottles.

[Christa reaches for a container representing one of the lexan bottles. It topples onto the floor of the mock-up mid-deck. Her comment shows her wonderful sense of humor, "Whoops…this zero gravity environment is just awful!"]

Two of these containers will be used. One has 1/2 water and 1/2 oil. The other contains 1/3 water, 1/3 oil, and 1/3 air. These can be compared to determine how the presence of the air affects the way the liquids behave. A marble is in each bottle to stir the mixture. Also, the teacher [*Christa*] will use a large quartz crystal to discuss the special conditions conducive to the growth of large crystals, especially relating to the growth of crystals in space. "

A Classroom Version of Christa's "Where We've Been and Where We're Going, Why?" Lost Lesson

The following demonstration replicates Christa's planned live lesson experiment:

Principles:

The crux of the second live lesson is fluid behavior in zero-g. The focus deals with fluid mixing behavior as well as settling behavior. An important facet of the demonstration is comparing these actions with earth-based techniques under the influence of gravity. While a qualitative demonstration is not complicated, the scientific explanations dealing with surface tension and other molecular forces are quite involved, perhaps, to a greater extent than the six filmed lessons. However, the discussion of differences between gravity forming and mixing phenomena versus zero-g results is useful. For example, the dropping of a raindrop earthward would be in "free-fall", i.e., in zero-g, but the added effect, friction, of air molecules contacting the falling drop would distort its spherical form. Such would not be the case aboard *Challenger*. No gravity would cause a drop of liquid to speed through the cabin atmosphere. These kinds of qualitative considerations would be a benefit of the live lesson mixing and liquid formation demonstrations.

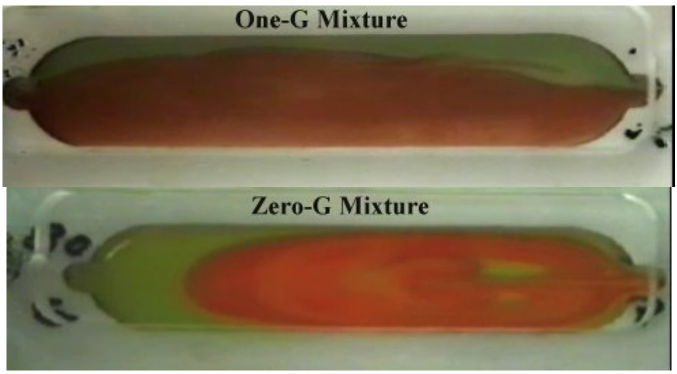
A principle which earth based fluids obey is "buoyancy", the separation of fluids by virtue of their density or "weight per unit volume" which cause lighter fluids to float on top of denser heavier liquids. Of course, without gravity, buoyancy is absent. In such an environment fluids of varying densities might be expected to mix more readily such that the resulting liquid is a uniform composite mixture. Earth based mixing depends on the physical shaking of the multi-fluid mixture to assume a uniform composition temporarily until the effects of buoyancy slowly separate the fluids once more. The use of gravity can be helpful in separate fluids of differing densities. For this reason, increasing the applied force above that of gravity makes a "centrifuge" useful in "precipitating" a material from a solution. The added centrifugal force acts to separate the solid substance from the fluid, depositing the precipitate on the bottom of the centrifuge test tube. In zero-g, such an apparatus would prove helpful in separating materials from a liquid solution, especially since gravity is not present to simply let settling work to form the precipitate.

Fortunately, among the video clips of Christa and others in the zero-g aircraft, are bubbles sailing about the KC-135 interior. These are, actually, produced by the effervescing tablet gas bubbles escaping inadvertently from the experiment container. In zero-g these would be expected to form spheres. However, because of the lightness, (i.e., small mass) of the air contained within the bubble formed by surface tension, these bubbles would have formed in a gravity environment as well. Indeed, they are simply the same manifestation as those bubbles produced by a child's bubble ring kit. Nevertheless, this is a useful scenario.

Liquids in orbit behave like soap bubbles on earth. It is because both have such little mass compared to the force of molecular surface tension. Also, the pressure of the air pushing on the bubble is equal to the gas within the bubble keeping the bubble inflated like a balloon. The effects of gravity do not distort ("pop") these spherical gas bubble shapes. [Note: Behind Christa, Bob Mayfield, and Barbara Morgan, a man throws a ball over their heads while they practice the experiment. The ball is thrown in a trajectory which bounds off the ceiling of the KC-135 aircraft. Based on the speed of the ball overhead, it would be expected to strike Christa, Bob, or Barbara. Instead, it simply continues above them as though gravity does not exist. This is added evidence how balls, liquids, bubbles and people behave in zero-gravity. They simply float in mid air.]

(Depress the "CTR:" key and click here to watch Christa inadvertently produce her zero-g bubbles.) The scene serves to demonstrate what Christa might have shown during the second life lesson scheduled for day-six of the *Challenger* mission. Additionally, the zero-g mixing demonstration could have been easily done in the KC-135 aircraft.

In fact, similar experiments have been done by NASA using that aircraft as a test bed. Below are a pair of videos showing the effect of zero-g compared to one-g on mixing of liquids of different densities. Their different colors differentiate them. Depress the “CTRL” key then click here for the mixing in a one g environment. Depress the “CTRL” key then click here for the mixing video in micro-gravity environment produced by a NASA zero-g aircraft.



Materials:

1. Soap bubble kit from dollar store
2. Bubble Gum
3. Spherical Balloons
4. Video camera
5. Eye Dropper
6. Dark Grape Juice

Performing the Live Lesson "The Ultimate Field Trip" in the Classroom:

1. Watch Christa's effervescent bubbles escape from their bottle container aboard the zero-g NASA aircraft.

2. Have a student create a stream of bubbles with the bubble kit.

3. Have another student blow up a bubble with bubble gum.

4. Ask the students to compare Christa's bubble with the soap bubble and the bubble gum bubble.

5. What is alike about all three of the bubbles? *Answer:* Each has air, or, a gas, within them. Each required someone or something to "blow up" the bubble to force the air inside to form the spherical bubble shape. Each has a material to contain or hold the air within the sphere. The balloon has a closed bag made of rubber. The soap bubble has an enclosed bag made of soap molecules, and the bubble gum has an enclosed bag made of gum. All have to deal with the equilibrium of gas forces on their respective "bags" of soap, rubber, or gum.

6. Next ask what was is not alike about the bubbles? *Answer:* The soap bubble and Christa's bubble have a thin liquid-like surface held together by "surface-tension" while the balloon and bubble gum have pliable solid materials providing the containing surface.

Analysis:

Study of thin films has fascinated scientists for centuries. Related to the topic is the examination of spheres of liquids and gases under the force of gravity and microgravity. The laws of gravity and buoyancy affect how gases and liquids interact. The interaction helps to explain and investigate the behavior of viscous and gaseous substances on earth and in space.

Whether on land, under the sea, in the air, or in space, instructive experiments contribute to study, teaching, and understanding physical and scientific principles of terrestrial or extraterrestrial living. Therefore, examining how a Shuttle zero g environment influences the forming of a fluid's geometry is important.

Of course, such study is readily done in the atmosphere when gravity in conjunction with air currents is not a factor. But in a closed room, without the influence of gravity or air currents, an ideal laboratory is present. Only the variables (forces) contributing directly to forming the geometric object need be considered. And best of all, the experimental environment is long lasting, hours, days, and even months (for the space station).

Though Christa's study of liquid properties in zero g was only planned for 15 minutes, this is years compared to the limited time available for a single flight of NASA's KC-135 zero g aircraft, *offering less than 25 seconds exposure to microgravity*.

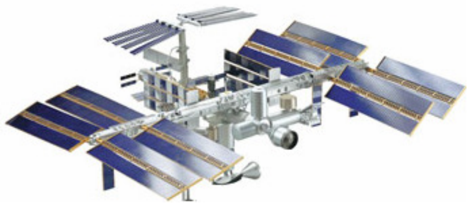
Since humankind first ventured into weightless space flights, examination of fluid behavior has revealed liquids assume a spherical shape in zero gravity. Perhaps, it was the Soviet dog Laika who first observed the phenomena on *Sputnik II* in 1958.

Numerous video clips exist in NASA's archives showing the principle Christa hoped to revisit during her fifteen minute live lesson. Click here with the ctrl key pressed. Watch an astronaut dispense fluid into his mouth. Note the sphere formed.

Christa's Unique Contribution

What Christa might have done beyond previous demonstrations dealt with her ability to teach. For example, she made the following comment about *helping kids understand constructing something when weightless*.

"Because I think it's hard for kids to realize that you can build something that's not attached to anything, but in zero gravity you can do that, so that at that point I wanted to let it (*space station model*) go." Christa personified the idea that a gifted teacher must first be a "teachable" student. An example of this is her interview with the manager of the International Space Station Program Office at JSC in 1985, Neil Hutchinson. Click here while depressing the *ctrl* key to experience that interview. Next, watch the video accessed in the following sentence to see how Christa integrated the interview into the lesson she planned. Hold down the *ctrl* key and click here to see how Christa's demonstration would have contributed to demonstrating zero gravity.



Wright Brothers' Airplane International Space Station

In Christa's demonstration, she holds up a model of the Wright Brothers' plane. Their aircraft was a glider with an engine. Knowing that a wing's lift is not needed in zero gravity, Christa might have thrust the model across the cabin. Obviously, it would have sailed exactly as it would have in a classroom. This would have demonstrated that space flight and airplane flight serve to overcome gravity. However, if she had thrown the space station model across the classroom, gravity would have destroyed it. Obviously, the space station would have been shown to be a "spacecraft" not an aircraft.

Questions to Answer:

1. Compare a scuba diver's environment to an astronaut's aboard the Shuttle. Could the diver conduct Christa's orange juice lesson using a colored liquid with slightly greater density than water? What would happen?
2. How does NASA use a swimming pool to train astronauts? How is this like working on board the Shuttle?
3. In the classroom, how would Christa's demonstration of the Wright Brothers' plane and the International Space Station have differed?
4. Do you think that the space station's wing-like solar panels are affected by air? If so, what is the effect, and how is it dealt with?
5. Should the space station be "stream-lined" like a jet aircraft? Why or why not?

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 differences exist on earth, not present for the Challenger demonstration?

2. Why would Christa's demonstration of how the space station is built work better on orbit than in the classroom on earth?

Instructions for using the attached CDROM and DVD

Included in the project are a CDROM and a DVD. The CDROM is provided in order to view the video clips supporting the text. The project was originated in *Microsoft Word*® 2003. To that end, the electronic book version on the CDROM replicates the printed version except that the videos can be accessed by holding down the *ctrl* key and clicking on the hyperlink opening the video.

The hyperlink feature of *Microsoft Word*® is used in the table of contents to access the pages containing desired content. The public domain program *OpenOffice* will directly open the video links without depressing the *ctrl* key.

A paper book may be made by printing the CDROM book version on 5.5" X 8.5" paper. However, a web-like *html* version is also included on the CDROM. In this version, all the videos and hyperlinks may be accessed without depressing the *Ctrl* key. Simply click on them.

Additionally, as a project research tool, the original NASA videos from which the project's study clips were edited are contained on the DVD. Both the CDROM and DVD are sleeved on the inside front and back covers of the project book. Included in the DVD video content are other activities associated with the training of the *Challenger* crew and, especially, the teacher in space candidates, Christa McAuliffe and Barbara Morgan. (The NASA video is designated as: *51-L Teacher Training Composite 3*, VJSC-955, Length:1:58:00.)

For added information or copies of the project, contact the project editor Jerry Woodfill, at ER7, NASA JSC, Houston, TX 77058. Phone: 281-483-6331, E-mail: **jared.woodfill-1@nasa.gov**

The project is a work of the Automation, Robotics, and Simulation Division of the NASA Johnson Space Center, Houston, Texas. As part of the *Space Educators' Handbook*, its ID identifier is OMB/NASA Report #S677.