Using the Space Program from Mercury to Apollo as Portrayed in the Movies *The Right Stuff* and *Apollo 13* and in the Mini-series *From the Earth to the Moon* as a Teaching Tool

James G. Goll

Department of Chemistry, Geoscience and Physics
Edgewood College, Madison, WI 53711
jgoll@edgewood.edu

Abstract

This chapter will examine how popular media related to the space program can be used to demonstrate the nature and motivation of scientific inquiry and science concepts. For over fifty years, the space program has inspired students of science and engineering. The United States manned space program from project Mercury to Apollo is the subject of two movies, *The Right Stuff* and *Apollo 13*, and the mini-series *From the Earth to the Moon*. Many documentary style television productions are available to supplement these movies and the miniseries. These documentaries provide recollections from astronauts, flight controllers, and flight directors. *Moonshot* and *To the Moon* chronicle the manned space program during the Mercury, Gemini, and Apollo programs. The documentary *To the Edge and Back* inspired the movie, *Apollo13*. The Science Channel's *Moon Machines* show many behind-the-scenes people who made the trips to the moon possible. The History Channel used the manned space program as a subject for several of its series: *Man, Moment, and Machine*, *Modern Marvels*, *20th Century with Mike Wallace*, and *Failure is Not an Option*.

Introduction

The movie *Apollo13* (1995) and the follow-up miniseries *From the Earth to the Moon* (1998), have been used to teach many chemistry concepts (1-5). *Apollo 13* has been shown to produce both high impact upon audiences and high utility for instructors when used as a teaching tool (6). The movie *The Right Stuff* (1983) provides insight into the Mercury program (7). Many popular media documentaries about the space program, such as public television's *To the Edge and Back* (1994) and *To the Moon* (1999), Turner Television's *Moonshot* (1994), *and* the Science Channel's *Moon Machines* (2010) show behind-the-scenes people who made the trips to the moon possible (8-11). The History Channel has several programs *Man, Moment, and Machine* (2006), *Modern Marvels* (2001), *20th*

Century with Mike Wallace Crisis in Space, The Real Story of Apollo 13 (1998), and *Failure is Not an Option* (2003 that contain recollections of the astronauts, flight controllers, and flight directors from Mercury to Apollo (12-15). Examples of teaching tools for scientific inquiry and chemistry concepts from these sources are provided.

Sending Astronauts to the Moon and Returning Safely to the Earth

How were people sent to the moon? *From The Earth to the Moon* has insight into developing a problem solving approach to sending humans to the moon. The method for going to the moon needed to be decided between the early front runners, direct ascent and earth orbit rendezvous, and the controversial lunar orbit rendezvous that required two spacecraft to link up in lunar orbit. John Houbolt favored lunar orbital rendezvous and was able to convince the managers and engineers that this method was the most feasible way to send humans to the surface of the moon. He successfully argued that only a small spacecraft could be landed safely on the moon. The risk of lunar orbit rendezvous was much less than landing a much larger spacecraft required by either direct ascent or earth orbit rendezvous methods.

Once the method was decided, new materials for rocket engines, spacecraft, and spacesuits were developed, software and computers were designed, and a communication system devised. The challenges to be overcome started with getting an astronaut in orbit, developing extra vehicular activities (EVA), rendezvous, docking, and long duration flight.

A series of spectacular rocket failures made the challenge of sending a human into space seem too risky. Careful analysis of the causes of failures and motivation from the cold war competition with the Soviet Union were required to overcome this problem.

The first spacewalk by astronaut Ed White indicated that working in space would be readily managed. Rendezvous, docking, and long duration flight were then demonstrated in turn. Longer extra vehicular activities requiring astronaut to work in space was the next challenge. The next three astronauts to do EVAs worked to the point of exhaustion. Newton's third law of motion, for every action there is an equal and opposite reaction, caused astronauts were unable to maintain their position when working in space. Improved footholds and handholds to hold the astronaut in place when working were added to the spacecraft. Better training in water tanks to simulate the conditions in space was implemented. This allowed astronaut Buzz Aldrin on Gemini 12 to work effectively.

Practice in Problem Solving

One of the great lessons that science students should glean from *Apollo 13* is that practicing problem solving is useful. Practice hones skills both for problems that can be anticipated and quickly solved and for problems that were not anticipated. While practice is important, integrating knowledge and critical thinking are often required to answer the complex problems.

The astronauts and the ground crew underwent extensive training in problem solving. Problems developed by the simulation staff were possibilities that mission control members and the astronauts would face. The astronauts and flight controllers would give their best effort to solve the problems. The astronauts and mission control team would then analyze the solution that was devised and implemented or the failure to develop a solution to see what improvements could be made. Data was evaluated to be sure correct action could be taken. This was an arduous process that continued until nothing more could be done all possible strategies were analyzed.

Gene Kranz described the debriefings as ruthlessly honest. These debriefings challenged the confidence of flight controllers and their ability to think critically and quickly. The simulations also required the astronauts and the controllers to reflect on their actions. This process developed trust, teamwork, toughness, and confidence. These attributes were instilled as part of the culture of mission control and were those valued by the flight directors. Gene Kranz clearly states this in many documentary-style programs such as *Failure is not an Option*.

Teaching Scientific Methodology and Content

The flight of Apollo 13 started off well. Liftoff has been described like shooting a bullet from a gun. The rocket goes 25000 mi/h and the astronauts feel four times the force of earth’s normal gravity as they travel through the atmosphere. This is the amount of gravitational force one may experience during a roller coaster ride. When the rocket undergoes staging, the crew flies forward in their seats because of inertia. This is called the “little jolt” in the movie. The crew is securely fastened in their seats so they move around as little as possible. The problem of an engine cut-off on the second stage rocket then appeared. The problem was quickly evaluated as the other engines compensated and the mission continued.

During the mission, a routine procedure to stir the oxygen and hydrogen tanks used to produce electricity and water resulted in an explosion that placed the astronauts' lives in danger. The tanks required periodic stirring since the supercritical fluids striated due to the motion of the spacecraft, just as the earth's atmosphere is striated due to gravity. Homogenizing the tanks' contents was required to get an accurate reading on the amount of material remaining. One of the hydrogen tanks was reading low and stirring would allow for a better reading. The movie shows the switch turned on followed by the rupture of the oxygen tank and the subsequent explosion that blew away the side of the spacecraft. The question may be asked during a class about why such a depiction is in the movie. How is it known that this is what actually happened? The answer can start with a discussion about the observation of the loss of electrical power and the cause of this apparent power loss.

At Mission Control in Houston, the first hypothesis was instrument failure, since the tanks had been stirred earlier in flight and so many independent systems should not show errors at the same time. Subsequent reports from the astronauts eliminated this possibility.

Aboard the spacecraft, initial hypotheses were also formed. The mission commander, Jim Lovell, suspected a prank by fellow astronaut Fred Haise, who would press the cabin repressurization valve, resulting in a loud bang. A quick glance at Haise dispelled this possibility. Haise then added his observation of the bending of the tunnel connecting the command module and the lunar lander and a new hypothesis was formed: the thin-skinned lunar module may have been hit by a meteor. The attempt to seal the tunnel connecting the lunar and command module to prevent the loss of atmosphere was unsuccessful. The continuation of life aboard the spacecraft proved that this explanation was not possible. Instruments indicated dropping levels of oxygen and fuel cells becoming inoperable. The computer restarted and communication was disrupted. The spacecraft was buffeting and difficult to control.

Lovell then made an observation that a gas was venting from the ship into space. This could be correlated with the dropping levels of oxygen and could also explain the buffeting of the spacecraft. At this time, the working hypothesis was that a meteor hit the ship, causing an oxygen tank to leak, which in turn caused the damage to the fuel cells. Near the end of the flight, the service module that contained the oxygen tanks could be seen. The observation indicated more extensive damage, which had to be explained. At the end of the movie, the cause of the explosion is revealed when Tom Hanks, in a voice-over, tells about a damaged coil.

How did they reach this conclusion? An investigation of the history of the oxygen tank revealed that the tank had been dropped about two inches. This caused damage to a metal tube used to drain the tank. The tank was filled during a test to determine if the liquid oxygen would not leak. When the tank was drained after the test, it did not drain quickly. Heaters inside the tank were turned on to aid in draining the tank. It was discovered from the specifications of the oxygen tank that the heater had incorrect wiring, so the temperature in the tank was eventually raised to several hundreds of degrees, conditions that allowed some of the insulation to crack and burn exposing the wiring. The exposed wires then created a spark that set the remaining insulation on fire and resulted in the sudden conversion of the oxygen in the tank to a gas. The pressure caused by the oxygen gas caused the tank to rupture and blow the side off of the spacecraft. This scenario was recreated in a laboratory and the result was the rupture of the oxygen tank.

Throughout *Apollo 13*, scenes depict the ongoing problems to be solved and the management of resources. The crew needed to change the course of the spacecraft to return to earth. The challenge of piloting the connected spacecraft with a different center of gravity caused Jim Lovell to comment that he needed to learn to fly all over again. Fortunately some testing was done earlier during Apollo 9 and Lovell was a quick study and was able to adjust the course of the spacecraft.

Another problem the movie shows is rising carbon dioxide inside the spacecraft. If the amount of carbon dioxide becomes too great in the blood, a person goes into a state of narcosis. This is a condition of confusion accompanied by possible tremors, convulsions, and eventually a coma. Eventually it is possible to asphyxiate. To solve this problem they needed to sequester much of the carbon dioxide. Apollo 13 used lithium hydroxide to remove carbon dioxide from the air in the spacecraft. However, the number of round lithium hydroxide containers was inadequate for the three astronauts. Scientist and engineers on earth needed to devise a method to adapt the square lithium hydroxide cartridges used in command module for use in the lunar module.

The amount of available energy on Apollo 13 once the fuel cells were no longer operating was limited to that stored in batteries. To conserve energy, almost everything in the spacecraft was turned off. This caused the spacecraft to become cold and damp. The amount of water available was also reduced when the fuel cells no longer operated. The lack of water and the cold conditions were causes on an infection contracted by Fred Haise.

Chemistry comes into play in *From the Earth to the Moon.* During one of the final tests of Apollo 1, a spark in the spacecraft started a fire that killed astronauts Gus Grissom, Ed White, and Roger Chaffee. The atmosphere inside the spacecraft was composed of oxygen at a pressure of about 850 torr, well above normal atmospheric pressure and the pressure of oxygen in the atmosphere. A pure oxygen atmosphere was used to minimize the amount of atmosphere needed to be taken into space. It also removed the complication of taking nitrogen out of the atmosphere in space. This was needed to prevent nitrogen from forming gas bubbles in astronaut's blood that cause the bends. The pressure was elevated to insure that the spacecraft was not leaking any of the internal atmosphere.

The increased oxygen concentration led to the rapid rate of the combustion of Velcro. Velcro was on the walls and was used to keep items from floating freely in the microgravity environment of space. In air, Velcro does not burn easily. In the oxygen rich environment of the spacecraft, Velcro burned very rapidly, almost explosively. In *From the Earth to the Moon*, the effect of oxygen concentration on the rate of Velcro combustion is dramatically demonstrated. This is a harsh but effective lesson on conditions causing changes in reactivity. It also serves as a reminder that safety must anticipate what might happen. Failure to anticipate the possibility of a fire during a high pressure leak check led to disaster. Investigation of the fire revealed other issues such as careless work and a high-pressure schedule that reduced safety. A culture of accountability and safety was reinforced afterward.

The first flight to the moon, Apollo 8, is chronicled in *From the Earth to the Moon*. A scene shows Sue Borman, the mission commander's wife, telling Chris Kraft, a senior NASA administrator, about her concerns about the mission to put her husband in lunar orbit. Kraft assures her that the simplest engine system is used.

A hypergolic mixture of hydrazine and dinitrogen tetroxide that required no pumps and would combust without any outside ignition source was used in the engine. The chemistry of this reaction is interesting. Dinitrogen tetroxide is in equilibrium with nitrogen dioxide and a small amount of nitrosyl nitrate. The Lewis structure of nitrogen dioxide does not obey the octet rule and this is correlated with its reactivity. This shows a structure–reactivity relationship that is so important in explaining reactivity.

The relative weakness of a nitrogen-nitrogen single bond caused by the lone pair repulsion on the nitrogen atoms of molecules like hydrazine is typically taught during an inorganic chemistry course. The weak nitrogen-nitrogen bond is the reason for the low activation energy; thus the reaction occurs when the reactants are mixed. Both the fuel and the oxidant are highly toxic and great care must be taken when handling them. They are both very corrosive, and therefore no engine using them including those used to land on and take off from the moon can ever be tested before they are used.

Comparisons can be between the nature of the rocket fuel and oxidant used for lift-off with the engines used in space and for the small maneuvering thrusters. The first stage used a kerosene-liquid oxygen system for maximum thrust and the second and third stages used hydrogen with oxygen. Since the spacecraft is still near the earth more complex system requiring an ignition source was usable since the astronauts would be able to return to the surface of the earth.

Apollo 12 has several scenes depicted in *From the Earth to the Moon* that can be used as teaching tools. It was raining on the day of the launch of Apollo 12*,* the second mission to the moon. Thirty-seven seconds after liftoff, the rocket was struck by lightning. What would cause the rocket to be struck by lightning since no lightning was observed in the area? The rocket, as it ascended, left a trail of gaseous ions created by the high temperature combustion of the kerosene rocket fuel. These gaseous ions, left behind in the contrail, made a good conductive pathway for the lightning to travel from the rocket to the ground. The lightning strike disrupted the telemetry data required to guide the spacecraft safely to the moon. The telemetry data needed to be restored or the mission would be aborted. Fortunately the curiosity of flight controller John Aaron paid off from an incident that occurred the previous year. A series of unusual readings occurred after a rocket had been struck by lightning. John Aaron remembered the pattern of readings and remembered a switch that could be changed to restore the required telemetry data. An instruction was given to the crew of Apollo 12 to change the Signal Conditioning Equipment to an auxiliary setting (set SCE to AUX), as this instruction provided an alternative pathway that restored telemetry data about the spacecraft to mission control.

A major goal of the Apollo 12 mission was to demonstrate that an extremely accurate landing could be accomplished. This goal was required both for crew safety and planning scientific investigations on the moon. Apollo 11, the first mission to land on the moon, missed its landing site by about four miles. Accurate landings would be required if the moon was to be explored relatively safely and systematically. Apollo 12 had a landing site near the unmanned lunar lander, Surveyor 3. An objective of the mission was to retrieve parts from Surveyor 3 to determine the condition of the spacecraft after years on the moon. The lunar lander needed to be within walking distance of Surveyor 3 for the mission to be totally successful. The Apollo 12 lunar lander touched down 535 feet or approximately one-tenth of a mile from Surveyor 3. In a classroom, missing a target by 535 feet is a large error, but if the target is a landing site on the moon, approximately 1.25 billion feet away from the Earth, it is very close. This point can be used to talk about the percent error and its difference from absolute error. The absolute error is the same but the percent error going to the moon is very small.

A safety point can be made based on Apollo 12. Astronaut Alan Bean was painfully reminded that instructions on checklist must be followed. He did not remove a camera from a window mount during reentry and it hit him in the head when it broke free from its mount on the descent to the ocean.

The Apollo 13 mission had a nuclear problem that is not shown in the movie but is brought out in *From the Earth to the Moon.* A small nuclear power source that contained 3.9 kg of plutonium 238, an alpha emitter with a half-life of 87.7 years, was in the lunar module, intended to be placed on the moon to power experiments. Fortunately the casing for the nuclear fuel was designed to survive an explosion of the rocket. The casing containing the plutonium, like the astronauts, apparently survived reentry since increases in radioactivity were not detected and when it came to rest with what remained of the lunar module in the Tonga Trench south of Fiji, approximately 6-9 kilometers underwater.

Astronauts as Scientists

After the goal of sending a man to the moon and returning him safely to the earth was met, why should any other mission be undertaken? The major political and technological objectives were achieved. Why should humans be sent to explore the moon, a dangerous and costly endeavor, rather than unmanned probes? Could robots in space collect enough information to find out everything we want to know about the moon? NASA asked these questions in deciding if it was worth the risk of sending humans to the moon for further scientific exploration.

Few astronauts had any significant scientific background, since most of them were selected based on their ability as test pilots used to living with the hazards of space flight. In *To the Moon,* Walt Cummingham stated the position of several astronauts as being anti-doctor and anti-scientist. Would a random sampling of rocks and dust from the lunar surface done by robots be better than relying on untrained observations of astronauts? The decision was made to educate the astronauts to become scientific observers for geological surveying and sampling.

From the Earth to the Moon shows details of how the astronauts were educated to be scientific observers. In *To the Moon*, astronaut Jack Schmitt, a geologist with his doctorate, stated that the test pilot astronauts were bored by traditional geology education. He realized that a more engaging, hands-on approach was needed which emphasized active learning field work rather than classroom lectures. The astronauts were taught to seek out unusual lunar samples that could provide clues to the history of the moon and the solar system by learning to collect samples and describe their context during field trips. Intellectually stimulating teachers, represented by Lee Silver and Farouk El-Baz, were able to get the astronauts motivated by simulating the observations that would be made during their missions.

The training of astronauts to become better scientists paid off during the mission of Apollo 15 when an interesting sample of crystalline rock was collected and taken to the earth. This sample was latter estimated to be 4.5 billion years old and was part of the primordial lunar crust. As mission commander Dave Scott said, "We went to the moon as trained observers not just to gather data with our instruments onboard, but also with our minds". That mission ended with "A little science on the moon," as Dave Scott stated. Scott paid tribute to Galileo by demonstrating that a falcon feather and a hammer indeed fell at the same rate in the vacuum on the moon.

The last mission to the moon, Apollo17, had Jack Schmidt on its crew. He would be able to use his education and training as a geologist on the moon. Schmidt was instrumental in the preparation of the astronauts and selection of the landing sites for the previous missions. As he and mission commander Gene Cernan were collecting samples, Schmitt noticed an unusual color on the lunar surface. As he examined the new location, he made careful observations, eliminated the possibility of light reflection, and concluded that it was the lunar dust itself that was orange. This discovery would have been less likely with unmanned probes on the moon.

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