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The Legacies of Apollo 11

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Fifty years ago this summer, three men aboard Apollo 11 traveled from our planet to the Moon. On July 20, 1969, at 10:56:15 p.m. EDT, 38-year-old commander Neil Armstrong moved his left foot from the landing pad of the lunar module (LM) Eagle onto the gray, powdery surface of the Sea of Tranquility and became the first person to step onto the lunar soil. Armstrong declared: "That's one small step for [a] man, one giant leap for mankind."[1] Nineteen minutes later, 39-year-old LM pilot Edwin "Buzz" Aldrin followed Armstrong onto the surface. Fifteen hours later, after spending two and a half hours outside of Eagle, the two men lifted off and returned to their command module (CM) Columbia, manned patiently by the third member of their crew, 38-year-old CM pilot Michael Collins. Four days later, the three men were back home. Although five additional lunar landings would occur, each more challenging and scientifically ambitious than its predecessor, Apollo 11 stands alone as the greatest technological accomplishment of the 20th century. The mission also signaled the beginning of the end of the "Golden Age" of America's space program.

One of the many charges of *The Physics Teacher* is to help teachers of introductory physics commemorate and raise the historical awareness in students of significant events in the history of physics. In light of this summer's 50th anniversary of the first manned lunar landing, this article provides teachers and students with an overview of the Apollo 11 mission and reflects on the enduring impacts of its "giant leap for mankind."

The mission

In bringing the Apollo 11 mission to the classroom, teachers must first make students aware of the tensions between the United States and Soviet Union during the Cold War of the 1950s. Fueled by the growing fear of nuclear weapons, threats to national security made in the media, rampant espionage, and war in Korea, space exploration became the new arena for the two superpowers to prove the superiority of their technologies and ways of life. On Oct. 4, 1957, Russia launched Sputnik, the world's first artificial satellite, into low Earth orbit. The "Sputnik crisis" prompted President Eisenhower to sign the National Aeronautics and Space Act on July 29, 1958, establishing NASA as the federal agency that would oversee the nation's exploration of space. The "space race" had begun! Against this backdrop, a manned lunar landing was conceived as the ultimate demonstration of technical superiority. Thus, the Apollo 11 mission actually began on May 25, 1961, when President Kennedy, speaking before a special joint session of Congress, committed the United States "to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth." To put the ambition of Kennedy's announcement in perspective, we have to recall that at the time of his address, NASA had only a 15-minute ballistic flight by astronaut Alan Shepard to its credit. From 1958 to 1963, the 11 flights (six crewed) of Project Mercury successfully put a man into orbit and returned him safely to Earth. From 1964-1966, the 12 flights (10 crewed) of Project Gemini established that humans could indeed survive in space for eight days, perform tasks outside of their capsules (i.e., "extravehicular activities"), and dock two vehicles in space—all feats that were necessary to land men on the Moon. Tragically, Project Apollo began on Jan. 27, 1967, when the interior of the AS-204 CM (later redesignated Apollo 1), occupied by astronauts Roger Chaffee, Virgil "Gus" Grissom, and Edward White II, caught fire during a "non-hazardous" test. By the time the ground crew was able to open the hatch, the three astronauts had perished.[2]

In December 1968, after an extensive overhaul of the program, a full Saturn V booster launched Apollo 8 on a circumlunar flight. The mission included a spectacular televised broadcast on Christmas Eve in which the crew sent back never-before-seen images of Earth (the first as seen by humans from another celestial body). Half a billion viewers from around the world listened to the crew read passages from Genesis, the first book of the Bible.[3] In a tumultuous year that saw assassinations, riots, protests, and war, the broadcast is considered transformative in its impact on our perceptions of Earth. In May 1969, the crew of Apollo 10 performed a full dress rehearsal of a lunar landing, flying the LM Snoopy 15.6 km above the lunar surface, where a powered descent would begin on the actual landing. By July 1969, NASA's goal was simple—"set foot on the Moon without dying."[4]

The crew of Apollo 11 was certainly an incompatible ensemble, at least in terms of temperament and interests (see Fig. 1). Even after the enormous fame brought to him by his historic feat, Armstrong continued to describe himself as "a white socks, pocket protector, nerdy engineer." Detached, introverted, and indefatigable, the native of Wapakoneta, OH, graduated in 1955 with a Bachelor of Science degree from Purdue University's aeronautical engineering program. He would eventually earn his Master of Science degree from the University of Southern California in 1970. Officials at NASA chose Armstrong to be the first man on the Moon because he lacked a large ego. Aldrin, on the other hand, was opinionated, outspoken, and brilliant. The Glen Ridge, NJ, native graduated in 1951 with a Bachelor of Science degree from the U.S. Military Academy at West Point and completed his Doctor of Science (ScD) at MIT in manned orbital docking techniques, earning him the nickname among fellow astronauts of "Dr. Rendezvous." If Armstrong was the no-nonsense engineer, Aldrin was the abstract scientist. He was at home with the high-level mathematics and technical aspects of the mission. He lobbied hard, albeit unsuccessfully, to be first on

the Moon. Interestingly, Aldrin owes his fame as a member of the Apollo 11 crew to his commander—Armstrong was one of the few astronauts who could work with Aldrin. When NASA officials offered Armstrong the chance to replace Aldrin as his LM pilot, Armstrong agreed to stick with his fiery crewmate. Finally, there was Collins, the consummate third wheel. Born in Rome, Italy, Collins graduated from the U.S. Military Academy at West Point in 1952 with a Bachelor of Science degree. Cool and self-deprecating to this day, Collins manned the orbiting Columbia in solitude as he waited for Armstrong and Aldrin to return from the lunar surface. For six months before the flight, Collins agonized about being the lone survivor of the mission. Since the ascent engine aboard the Eagle had never been fired on the surface of the Moon, Collins feared that his two crewmates might be stranded there beyond his reach. While Armstrong and Aldrin became household names, few people today can identify Collins as the third member of the crew. However, in contrast to his crewmates, Collins emerged from the Apollo program unscathed personally. As Aldrin struggled with alcoholism and depression, Armstrong became somewhat of a recluse. Collins retired from the U.S. Air Force as a major general and served as the first director of the National Air and Space Museum.

Teachers and students interested in additional information will find plenty of historical works that provide extensive details of the momentous mission.[5-10] In particular, the autobiographical account of Michael Collins, *Carrying the Fire: An Astronaut's Journeys,* provides a candid insider's assessment of the personalities of the astronaut corps. For example, Collins asserts that crewmate Buzz Aldrin "would make a champion chess player; always thinks several moves ahead," yet notes that Aldrin struggled with being the *second* man on the Moon: "Fame has not worn well on Buzz. I think he resents not being first on the moon more than he appreciates being second." Collins goes on to praise Armstrong: "Neil is a classy guy, and I can't offhand think of a better choice to be the first man on the moon." On Armstrong's contemplative nature, Collins writes: "Armstrong savors [decisions]—rolling them around on his tongue like a fine wine and swallowing them at the very last moment."

After their safe return, the three astronauts were consumed by tickertape parades and a world speaking tour. Five additional missions, Apollos 12 and 14–17, landed on the Moon between Nov. 1969 and Dec. 1972. Although these later missions spent increasing amounts of time on the surface and achieved some spectacular first feats of their own, none of them generated the enthusiasm of Apollo 11. Excitement surrounding manned exploration of the Moon died within three years and with it the "Golden Age" of Apollo. Humans have not set foot on the Moon since Apollo 17 commander Gene Cernan left the surface in 1972. As Neil Armstrong observed: "I fully expected that, by the end of the century, we would have achieved substantially more than we actually did."[11] This July, only two members of the crew of Apollo 11 will be celebrating the historic mission—its commander passed away in 2012. Looking back, we now see Apollo 11 as an anomaly. The mission came at a unique moment in time when a president could set forth a major goal for the space agency and expect nationwide public support and almost unlimited resources to achieve that goal. However, with 50 years of hindsight, we can share several legacies of the Apollo 11 mission with our students and commemorate the golden anniversary of mankind's first lunar landing.

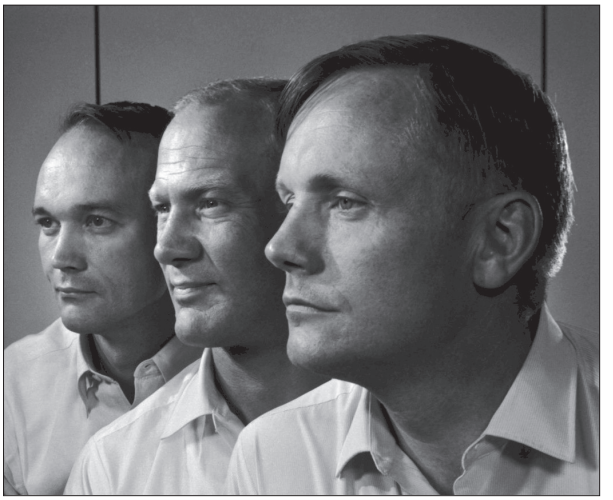

Fig. 1. Apollo 11 crew. Left to right: Michael Collins, Buzz Aldrin, and Neil Armstrong. (Courtesy of NASA)

Legacies

First, Apollo 11 is the greatest feat in the history of piloted flight and arguably the greatest technical feat of the 20th century. In addition to safely ferrying humans to the lunar surface and back, Apollo bequeathed us an expansive list of practical inventions and technical spin-offs that revolutionized how we live today: athletic shoes, computer chips, conditioning and sports equipment, cooling suits, cordless power tools, flame-resistant textiles, freeze-dried foods, joysticks, insulation, life-support systems, lubricants, measurement techniques, medical diagnostic machines, memory foam, recycling fluids, reflective materials, safety systems, and space suit technologies (to name a few).[12] Interestingly, the Apollo program's greatest spin-off may have been the lessons learned from its management. Never before had such a unique combination of political climate, cutting-edge technical capacity, and a competitive public drive been coordinated to turn a president's dream into reality. As Roger Launius, former chief historian for NASA, notes: "NASA leaders had to acquire and organize unprecedented resources to accomplish the task at hand. From both a political and technological perspective, management was critical."[13]

Second, history books will long remember the Apollo program as changing several of our perceptions. For starters, the program changed our perceptions of spaceflight and the exploration of other worlds. *Twilight Zone* creator Rod Serling once said, "Fantasy is the impossible made probable. Science Fiction is the improbable made possible."[14] Apollo 8 made spaceflight to other worlds probable. Apollo 11 made their exploration possible. Next, the program changed our perceptions of ourselves. On Dec. 24, 1968, during the fourth lunar orbit of the Apollo 8 mission, LM pilot Bill Anders peered out

Fig. 2. Earthrise photo. (Courtesy of NASA[19])

of his spacecraft's window and snapped the first colored images of Earth taken by someone not on it.[15] Anders described Earth as a "blue marble" hanging in the blackness of space. The picture is known simply as "Earthrise" (see Fig. 2). The iconic image has become what some claim is "the most influential environmental photograph ever taken" because it forced humanity to see Earth as a beautiful but fragile oasis in a desert of darkness.[16] In some sense, the modern environmental movement owes a debt of gratitude to the Apollo program for creating the crystallization point about which the movement rallied. By no coincidence, Earth Day was first celebrated in 1970. As Anders observed, "We set out to explore the Moon and instead discovered the Earth."[17] Teachers and students may enjoy a history of the Apollo 8 expedition, based on NASA records as well as interviews with the crew, published in 2018 to coincide with the 50th anniversary of the mission.[18]

Third, after setting foot upon the lunar surface, Armstrong immediately put a "contingency" rock into his pocket in case he and Aldrin had to abort the landing and make a hasty departure.[4] At least they would have a souvenir for their troubles. Less than a year later, the crew of Apollo 13 inscribed the Latin phrase "*Ex Luna, Scientia*" ("Out of the Moon, Science") on its insignia (although the lunar landing was aborted). Apollos 15-17 brought a rover to the lunar surface to increase the area over which samples could be recovered. On the final Apollo mission, astronaut and professional geologist Harrison Schmitt surveyed the lunar landscape. In total, the 12 Apollo moonwalkers spent 25 man-days on the lunar surface and returned over 840 pounds of samples. Clearly, the Apollo program was something more than just proving we could "set foot on the Moon without dying." Aside from the improvements in technology and engineering, Apollo missions were advancing the natural sciences. The case can be made that Apollo laid the foundations of modern planetary science. Even today, Apollo's lunar samples, unobtainable on Earth, help us understand the geological history of our planet and Moon.[3] These samples have led to the successful determination of the lunar cratering rate, improved our understanding of the origin and chronology of the Moon's history, and provided reliable calibration standards for remote sensing of unexplored locations on the Moon.

Fourth, the Apollo program accomplished its primary *political* goal—landing a man on the Moon and safely returning him to Earth before 1970. No greater testimony to the political drive behind the Apollo landing can be provided than a picture taken at the end of the mission of jubilant flight controllers at Houston's Mission Control Center. Behind them on the MCC's huge central screen is Kennedy's 1961 speech followed by a simple proclamation, written in bold scripted font: "Task Accomplished ..... July, 1969."[13]

Last, America's piloted programs of the 1950s-1970s were a public works effort comparable in scope to the building of the Panama Canal or Manhattan Project. Critics of the space program assert that these programs were a colossal waste of money. Indeed, going to the Moon was expensive. Calculating the costs of these programs is difficult, but consensus estimates that Project Mercury cost $277 million (over five years) in 1965 dollars; Project Gemini cost $1.3 billion (over six years) in 1967 dollars; and Project Apollo cost $25.4 billion (over 12 years) in 1973 dollars. In today's dollars, the three projects cost a combined $118 billion. *Shouldn't we have spent our money on more pressing problems on the ground*? Perhaps … but this argument implies that the money used to fund these programs was simply buried in a treasure chest somewhere in the lunar soil. Instead, this money employed a lot of people *on the ground,* for a long time. For example, NASA's Langley Research Center estimates that Project Apollo alone employed 400,000 Americans and required the support of over 20,000 industrial firms.[20] Furthermore, here lies a wonderful opportunity for teachers to bring visibility to the diversity of people that worked behind the scenes to put human beings on the Moon. A good lead-in to such classroom discussions is the mission's iconic insignia depicting an American bald eagle carrying an olive branch to the lunar surface in the spirit of peaceful exploration. Designed by Collins, the crew decided collectively to keep their names off the insignia, wanting "the design to be representative of everyone who had worked toward a lunar landing."[5] Armstrong insisted the insignia's number "11" be designated in Arabic numerals because he wanted it to be easily understood by all people. Bringing to light some of the unsung heroes of the mission—not just the astronauts who were catapulted into the public eye—adds a human perspective to the historic event. For example, no better testimony to the diversity of people who made the lunar landings possible can be made than "Hidden Figures," the 2016 biographical movie that tells the story of Katherine Johnson and other African-American female mathematicians who worked at NASA during the space race. Next, Greg Wiseman, an audio engineer at the Johnson Space Center, and his colleagues have digitized and catalogued thousands of hours of audio from the Apollo 11 mission. The audio represents over 600 different individuals involved in the mission. As Wiseman explains: "Landing on the Moon wasn't just Neil Armstrong. It was an entire team of people working together to make it happen, and all of this audio is their side of the story." The

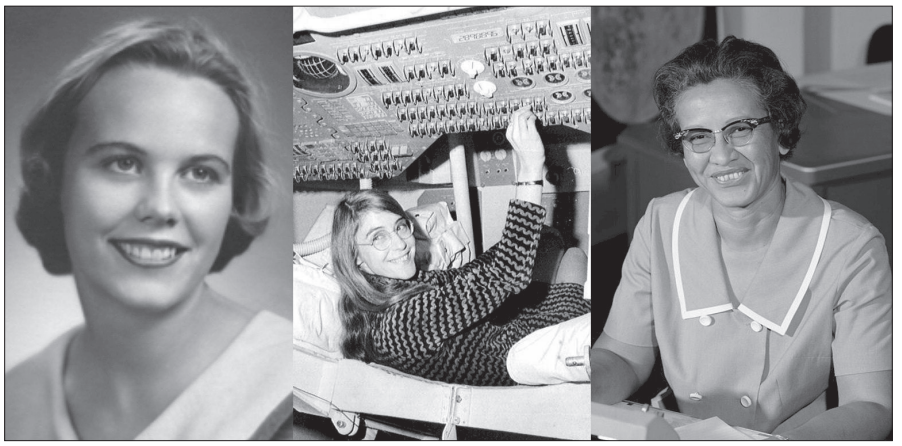

Fig. 3. "Hidden Figures." Left to right: Susan Finley, Margaret Hamilton, and Katherine Johnson. (Courtesy of NASA)

files are available at https://app.exploreapollo.org/. Finally, Nathalia Holt's book *Rise of the Rocket Girls: The Women Who Propelled Us, from Missiles to the Moon to Mars* tells the story of an all-female team of coders whose work was crucial to the success of the Apollo 11 mission.[21] Among others, the book focuses on Susan Finley, who worked on NASA's communication system, and Margaret Hamilton, who was the lead Apollo software designer (see Fig. 3).

Apollo 11's greatest legacy

As important as the aforementioned legacies are, the greatest legacy of the Apollo lunar landing program is the generations of young men and women that it inspired to enter STEM-based careers. Research supports the notion that the strongest influences on an individual's decision to enter a profession occur well before entering college.[22-25] Studies have found that students who were successfully recruited into various STEM-professions were motivated by an early, informal exposure to STEM under favorable working conditions and with positive experiences.[26-28] Personally, three such experiences led *me* to physics: working on science fair projects with my dad, watching the first run of Carl Sagan's *Cosmos: A Personal Voyage* (having Sagan for class seven years later didn't hurt either), and watching the Apollo lunar landings. Fortunately, my dad was a space enthusiast who understood the significance of the Apollo program. Although his children would rather have been watching reruns of *Speed Racer* or *Batman*, my father made his children watch the televised landings. I remember sitting in front of my grandparents' black-and-white television as Apollo 11 broadcasted from Tranquility base, my dad emphasizing that we were witnessing history. The next morning, and for several months after, my brother and I started each day with a hearty glass of Tang®, "the drink of astronauts," in the hopes of one day walking on the Moon.[29] For Christmas that year, I received a Snoopy action figure depicting the "Peanuts" beagle in a bubbled space helmet and carrying a life-support pack. The 1960s toy, battered and faded by time, overlooks my home office to this day. (Would you believe a vintage one sold on auction for over $1300?) Three years later, I sat spellbound and horrified at the night launch of Apollo 17: "*How can they steer the rocket in the dark*?" I worried. Even at that early age, I wanted to understand the events I was witnessing. I was hooked!

Recently, my 13-year-old daughter and I saw the movie "First Man," last year's bio-drama based on the life of Neil Armstrong. Sensing her interest in Armstrong's accomplishments, I took her on the three-hour drive from Cleveland to Wapakoneta, OH. Our first stop was 601 West Benton Street, a property appropriately named "Eagles Landing" (see Fig. 4). There stands a modest two-story home that Stephen and Viola Armstrong purchased in 1944. Neighborhood homes are only a few feet apart, and the church where young Neil went to Boy Scout meetings is just down the street. One can easily imagine him bicycling to the corner ice cream store. Visitors to Neil Armstrong's boyhood home will be struck by how ordinary it is. The take-home message is clear—not everyone can become the first person to set foot on the Moon … but that person can be anyone!

Next, we visited the Armstrong Air and Space Museum. We saw the plane in which the self-described "nerdy engineer" learned to fly. Also on display were his grade school and high school memorabilia, Navy regalia, Gemini 8 spacesuit and capsule, and Apollo 11 back-up suit. The museum houses countless interactive exhibits and is well worth the visit. Just before we left the museum, my daughter tried her hand at the Apollo 11 lunar module simulator. She refused to leave until she successfully landed the Eagle on the lunar surface. Eventually, she pulled off the landing, which I was unable to accomplish. As we left, her face beaming with pride at being "the first woman to land on the Moon," she looked at me and asked, "Do you think I could land on the Moon someday?" She was hooked! The legacy of Apollo 11 continues.

Fig. 4. Visiting "Eagles Landing."

Acknowledgments

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