Five Centuries of Exploration: From Distant Shores to Distant Planets

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For millennia, humans' innate curiosity about their environment has fueled a desire to explore, leading men and women to cross vast oceans and unmapped continents on Earth and, in recent decades, to probe the endless reaches of interplanetary space. While exploration has been a key feature of nearly every civilization, historical records show that the past five centuries—starting with Europe's "Age of Discovery" in the early fifteenth century, when navigators sought to map the planet—constitute an era of intense technological development aimed at expanding the boundaries of the known world (Figure 1).

Seeking more insight into what connects past and present explorers, ten Belgian high-school students who excel in science and mathematics attended a seminar titled "An exercise on exploring space," held on 16 March 2010 at the Katholieke Universiteit Leuven in Belgium. There they were invited to compare Christopher Columbus, Vasco da Gama, Hernando de Cortés, Ferdinand Magellan, and other European explorers who traversed the oceans over 500 years ago to the men and women who pioneered and continue to advance the exploration of space.

The students were given five topics to address: how explorers prepare for a voyage, the transportation and technology needed to survive it, the risks such a journey entails, how to minimize those risks, and the potential benefits of the mission. Students spent time brainstorming about and discussing each topic, searching for both parallels and contrasts between the obstacles faced by explorers during the Age of Discovery and the space travelers of today. Even if these students' reflections did not represent all the objectives of the scientific community, it was nonetheless interesting to hear thoughts from the generation that may have the chance to see humans land on Mars.

After identifying the similarities between early explorers and space travelers, the students separated them into two categories: (1) issues that directly mirror each other (for example, explorers have always needed patrons to fund their voyages and have had to tailor their objectives to fit their sponsors' budgets), and (2) issues where comparable motivations exist but are manifested in very different ways. An example of the second category would be the environmental conditions encountered in interplanetary space, which differ radically from those faced by Columbus and his contemporaries—space weather conditions beyond the stratosphere are unlike anything that humans experience on Earth. But whether the explorer must endure an ocean storm or a solar storm, his or her objective remains the same: to lead the vessel and crew into unknown territory and return with first-hand knowledge of new worlds. Results of the students' brainstorming sessions are described below.

Preparing for the Voyage: Politics, Funding, and Finding a Crew

The Age of Discovery spanned just over two centuries, and during that period many Europeans were willing to venture into what was then referred to by the Latin term *Terra Incognita*, meaning "unknown land." These brave sailors were drawn by the promise of wealth or the glory that would be bestowed on the discoverers of new and faster trade routes. Some were also motivated by imperial ambitions, hoping to claim new territories for whichever of the rival European powers they served. In a similar way, at the dawn of the space race in the late 1950s, nations vied to be the first to orbit Earth, to launch a manned spacecraft, and then to land humans on the Moon. The next milestone will likely be sending humans to Mars.

In the past, expeditions were funded by kings and queens

Figure 1. Five hundred years of exploration: Crossing the oceans on Earth to voyaging through the vast reaches of interplanetary space.

or other nobility as part of the struggle among European nations for economic dominance. Exploration and politics have often been inseparable, and while direct cost comparisons are difficult to make, it is clear that the cost of constructing a spacecraft greatly exceeds the sum that was required to build a seaworthy ship in fifteenth-century Europe. Finding sponsorship was nevertheless just as vital an issue in the days of Columbus as it is today. Up to now only national space agencies have had the means to underwrite space missions, but private-sector sponsors of space travel are beginning to emerge. Unlike the captain of an early modern sailing vessel, the captain of a spacecraft is not expected to secure funding for his voyage or to oversee the construction of his ship. Nor is he or she expected to pay crewmen's salaries or to buy provisions for the journey.

Five hundred years ago a ship's officers were generally far better educated than its crew. Columbus, for example, possessed a good knowledge of cartography and navigation, while many of his crew likely had very little schooling. Some were experienced seamen (see http://www.christopher-columbus.eu/ships-crew.htm), but some were not; some were hired just days or weeks before a ship set sail, and occasionally amnesty was offered to convicts who signed on to these voyages. In contrast, not only the captain but the entire crew of a spacecraft must be highly educated and hold the highest level security clearance. Once selected, all crew members undergo long periods of training before they actually embark on a mission. Preparation often takes more than a decade and requires a highly skilled interdisciplinary team.

Transportation and Technology

In the Age of Exploration compasses, sextants, and telescopes were used with great effectiveness. In fact, it was improvements in cartography and navigational technologies that helped to make sea exploration possible. Transportation in those days depended on wooden sailing ships, such as the carrack and nau, the three- and four-masted sailing vessels developed in the fifteenth century by the Portuguese. These ships were full of hazards, and the loss of multiple crewmen, though lamentable, was considered routine. Many sailors perished from disease or, if adequate supplies could not be acquired, from hunger and thirst.

Sending humans into space has required similar technological breakthroughs. These include propulsion systems to launch humans off the planet, habitable modules to keep them alive in the void of space, and mechanisms for bringing them back to Earth. Further, as knowledge of space radiation's harmful effects has grown, better shielding has been developed. For successful interplanetary travel, engineers and space scientists will have to make other technological leaps: various alternative propulsion methods, such as propulsion through fusion, antimatter, and light sails (see http://www.physorg.com/news8817.html), are now being studied. But the amount of acceptable risk to space crews is much lower for astronauts than it was for sailors of Columbus's day. Spacecraft have numerous safety systems to ensure the crew's safe departure, voyage, and return to Earth. Losing a crew can not only compromise a mission, but as with the Apollo 1 flight and the explosions of the Challenger and Columbia shuttles, such losses can also deal a serious blow to the morale of the nation that launches a failed mission.

In the fifteenth and sixteenth centuries, once a ship left port, the people on board would be cut off from their patrons, sponsors, and families for months and sometimes years on end. Today, however, except for occasional signal time delays, astronauts can remain in near-constant contact with their home base. Relaying signals between satellites located at specific orbits near Mars may be one way to ensure reliable radio communication on a round-trip mission to Mars, which scientists estimate will take about 2.5 years to complete with existing technologies.

What Are the Risks of Exploration?

Today's explorers know a great deal more about the "oceans" that must be crossed to reach Mars than European explorers knew 500 years ago when they first set sail for the Americas, India, and the Spice Islands. Robotic scientific missions have already been sent to Mars, providing space scientists with data from both direct and remote-sensing observations. By continuously observing the Sun, scientists can study its influence and can monitor local space weather for Earth and for other planets as well. Future interplanetary missions will undoubtedly be equipped with space weather forecasting devices. This contrasts sharply with early seafaring expeditions, when weather prediction was nonexistent. Columbus and his contemporaries had to rely on what they could see combined with their past experience of weather conditions at sea.

When early explorers finally arrived in *Terra Incognita*, they had no idea what to expect or what they would encounter with respect to local inhabitants, extreme weather conditions, health hazards, etc. En route they were often afflicted with scurvy, a potentially fatal disease caused by a deficiency of vitamin C; it was not until the late 1700s that the British navy understood that scurvy could be cured by eating citrus fruits. Many ships had no medical personnel and very little in the way of medical supplies. Lack of fresh water and spoiled foodstuffs were chronic problems when voyages took much longer than originally planned. After months of confinement aboard ship, with no notion of when they might next see land, sailors were prone to thoughts of mutiny. Astronauts, by contrast, are well prepared for the isolation of space. Because future missions are likely to last for several years, astronaut candidates are chosen not only for their academic credentials but also for their ability to manage stress and endure long periods of confinement.

Many of the physical and physiological demands of human adaptation to spaceflight have been well studied. Space biology encompasses such topics as how zero gravity affects the human body (for example, loss of bone and muscle mass, "puffy faces and chicken legs," shrinking of heart tissue) as well as how gravity affects the reproduction, development, growth, and aging of animals and plants. The most serious questions concern the effects of space radiation on cells and the cancer risk faced by astronauts. Mission limits, valid for male crew members above the age of 35 and female crew members above the age of 45, are not to exceed a 3% statistical increase of cancer risk (*National Council on Radiation Protection and Measurements*, 2000).

Most analysts agree that energetic particle radiation represents the greatest hazard to humans in space. Specifically, the high-energy galactic cosmic rays (which can breach the heliosphere in larger numbers during solar minimum) and sporadic solar energetic particle events (which typically strike during solar maximum) can knock electrons free from molecules that make up the cell, disrupting its normal functioning. Cells that reproduce rapidly (for example, in the skin, eyes, and blood-forming organs) are the most susceptible to damage because they cannot repair themselves easily while replicating. The most severe damage results when the DNA molecule is affected. Acute radiation effects include diarrhea, nausea, vomiting, and changes to blood chemistry; more severe effects include central nervous system damage or even death. However, the major concern about space radiation is the long term effects on astronauts that can include cataracts, increased chance of cancer, and sterility, as well as passing on mutated genes to the next generation. In contrast to the era of seafaring explorers, these harmful effects are the subject of many research endeavors; the risk of radiation is frequently discussed at conferences [e.g., *Crosby et al.*, 2008], and many studies have been performed [e.g., *Foullon et al.*, 2005] concerning health issues associated with radiation encountered by humans in space.

Research efforts have also focused on developing new types of shielding material capable of preventing exposure to secondary radiation. Secondary radiation can be generated by the shielding material itself and can be more hazardous to astronauts' health than primary space radiation. When particles of space radiation collide with atoms in the shield, they trigger tiny nuclear reactions. Those reactions produce a shower of nuclear byproducts (for example, neutrons and other particles) that penetrate the spacecraft. These particles can also disrupt the normal functioning of cells. Scientific understanding of solar energetic particle events is rapidly evolving and should soon allow for more accurate space weather forecasting, which will enable space travellers to know when to take shelter in more heavily shielded parts of the spacecraft. Nathan Schwadron of the University of New Hampshire and a host of colleagues at various institutions recently began work on the Earth-Moon-Mars Radiation Environment Module (EMMREM) project (see http://emmrem.unh.edu/index.html), the main objective of which is to develop a numerical model that can characterize time-dependent radiation exposure in the Earth-Moon-Mars and interplanetary space environments [*Schwadron*, 2009].

How Can the Risks Be Minimized?

Before any mission takes place, extensive risk analysis is performed in an effort to anticipate conditions and hazards in space. This involves testing onboard electronics to assess their vulnerability to adverse space weather as well as modeling the space radiation environment. Spacecraft shielding is then designed on the basis of these test results while also taking into account mass, weight, and cost issues. Protective suits are designed for astronauts when they perform extravehicular activity, and the spacecraft is equipped with special shielded rooms to protect the crew against radiation from solar storms.

In the days of Columbus, however, very little was known about the environments the crew would face on their voyage or when they reached their destination. Further, medical expertise aboard ship was crude by today's standards. In contrast, every space mission includes a crew member with medical expertise as well as essential medicines and the capability to perform in-flight surgery with guidance from a surgeon on Earth. Spacecraft must also carry food provisions for the entire trip and have water recycling capability. In contrast, access to fresh food and potable water were never assured on long sea voyages. Early explorers also faced the risks of piracy while at sea and a hostile reception from indigenous peoples when they landed. Ships were therefore equipped with artillery and other weapons for self-defense. Will future spaceships also include artillery, as in science fiction movies?

What Are the Possible Benefits of Exploration?

As Earth's population increases, so does global competition for limited natural resources. This, in turn, aggravates the ongoing problems of environmental degradation. Humans have therefore begun to look toward space for solutions to these problems. Future generations may look even farther away to newly discovered planets, or the day may come when humans are forced to leave the Earth. With this in mind, space entrepreneurs are already calculating the economic viability of industries such as lunar and asteroid mining. The explorers of five centuries ago were also seeking new trade routes and new sources of wealth, but in general the motivations for their expeditions were more for gain than necessity.

Space exploration does not lead just to advances in physics, engineering, and medicine. It inevitably prompts humans to ask several profound questions: How did life evolve? Are we alone? What is the meaning of life? Is there a God? Seafaring explorers faced similar questions: Is the Earth flat or round? Are there other civilizations on distant shores? Answering these questions led to great leaps in the evolution of modern thought and the perception of the individual's role within a vast and unfamiliar environment. Will the questions inspired by space exploration shape the philosophical development of future societies?

What lies ahead?

Twenty generations have passed since Christopher Columbus and other explorers crossed the oceans to explore new continents and discover new lands and new civilizations. Now humans are capable of exploring other planets in our solar system. Will they find life on other worlds?

The renowned physicist and cosmologist Stephen Hawking has suggested that extraterrestrials are almost certain to exist, and he recently made the following observation: "If aliens ever visit us, I think the outcome would be much as when Christopher Columbus first landed in America, which didn't turn out very well for the Native Americans" [*Leake*, 2010]. Might humans behave similarly if they encountered life on other planets in other solar systems? Other opinions exist, of course, such as the one proposed by the late astronomer Carl Sagan, who believed that the contradiction between a large number of extraterrestrial civilizations being formed and the absence of any evidence of such civilizations is due to the tendency of technological civilizations to destroy themselves rather quickly.

Regardless of what is out there, humans will be compelled to explore it. The Russian-born scientist and mathematician Konstantin Tsiolkovsky, who is often referred to as the father of astronautics and human spaceflight (http://www.nasa.gov/audience/foreducators/rocketry/home/konstantin-tsiolkovsky.html), summarizes the motive for space exploration in a single sentence: "Earth is the cradle of humanity, but one cannot live in the cradle forever."

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