UNIVERSITY OF NOTRE DAME

April 27, 2017

Comments from undergraduate students' written reflections after attending "The Value of the Moon: Creating a Permanent Cislunar Transportation Infrastructure," a *Challenges and Innovation in Civil and Environmental Engineering and Earth Sciences* seminar presented by Paul Spudis, Senior Staff Scientist, Lunar and Planetary Institute, Houston, TX, on April 20, 2017 at the University of Notre Dame.

In this presentation, Paul Spudis of the Lunar and Planetary Institute talked about his ideas for the future of United States involvement in space and his plan to establish the moon as a stepping stone for other space travel. He first focused on the need for the US to develop a space program that is relevant to our national needs. He wanted to change the classic model of space exploration of going on a mission and discarding the rocket and then starting over again. His goals were to establish a US presence in cislunar (between the earth and the moon) space so that by being a player in the picture we can help ensure fair and free interactions in space. He feared if China monopolized cislunar space, they would use it as a military strength. His goal for the moon operation was to use the moon to provide raw materials such as water, rock, solar energy, and fuel to make it possible for us to go throughout cislunar space and to Mars and to gradually expand the reach of humanity. Using the ice stored in the moon he proposed to create water, crack this water into hydrogen for fuel and oxygen to breathe. He then planned to establish an outpost on the moon from which we could more easily launch missions because the gravity field is less. He said all this could be accomplished within the budget of NASA. This was an incredibly interesting talk that proposed a dream for the future of humans in space that was very convincing. When hearing his proposed technologies to be able to survive in an extraterrestrial world, I wondered why we hadn't implemented some of these strategies in our lives on earth already. If the most efficient rocket fuel can be obtained from water, why don't we power our vehicles by this method today. Much engineering and testing of his proposed technologies would have to be done on earth before they were used in space and perhaps they could be applicable to environmental solutions down here as well.

I thought this presentation was important in that it really showed a major issue that our generation is going to have to tackle. Not only do we need to get back out in space but we also need to work out the laws that will govern it. This presentation was also an interesting look at a field where you might not be able to test out your ideas until the real deal, thus making your prep work all the more important in terms of accuracy, effectiveness, and efficiency.

The first, and what I believe was the most important, point made by Mr. Spudis was that the paradigm of space travel needs to change. Space travel has often been about beating another country to a certain point in space or achieving a certain technical feat before other countries do. It has not been about the ability to go anywhere for any length of time. We need to rethink what space travel can offer our world in terms of technological innovation and economic value. An analogy Mr. Spudis used was sea faring. Space is an unexplored ocean with untapped resources. These resources include economic interests dealing with weather, mapping, and navigation, scientific interests in the areas of earth science and

astronomy, as well as national defense interests involving the Navy. Clearly, space has more to offer than one might think.

The best way for the United States to respond to other countries' space programs is simply to be there; to be in space and a part of a process so we have a say in what happens. The moon is extremely important because it is close, interesting, and useful. The closeness of the moon to Earth allows room for error if something goes wrong. The moon is useful because of the several materials on the moon such as metals and water. The ultimate goal is to extend human reach beyond lower Earth orbit, creating a permanent space infrastructure. Instead of spending money and time on a project that will eventually go away, spend on infrastructure.

This talk was relevant to my career as a civil engineer because it reinforced the importance of utilizing all of one's resources and taking on tough challenges. One of the points Paul Spudis made was that technological breakthroughs come when tough challenges are confronted. Taking on complicated situations forces one to think outside the box and exercise creativity. As a civil engineer, it will be crucial to exercise creativity alongside the rigidity and safety provided by the building codes.

I found this talk quite interesting because it offers a very practical way to extend space exploration into the future that will be resilient to different administrations and varying priorities with regard to federal expenditure. The stepwise progression of the system is more sustainable than attempting large missions that do not create lasting infrastructure, which makes it a more viable option.

He posits that the past and current paradigm of space travel has been disposable, publicity-stunt-driven one-time-runs and proposes that the future objective should be freedom of movement in space. A key aspect of this objective is the moon; since spacecraft leaving earth are mass- and power-limited by the Earth's gravitational pull, the moon offers a nearby, but physically favorable staging ground. He also proposes that the value of space is beyond just a news-headline "wow-factor". There is a carrot and a stick to space exploration. The positive incentives include improved imagination, large-scale problem-solving, diversification of the location of the human species to ensure survival, and scientific understanding, to name a few. More ominously, but perhaps more practically motivating, is the idea that a nation is either space powerful or space vulnerable—and those who are present make the rules. China, for example, has rapidly expanded their military-run space program. Though they do not pose a current threat, Dr. Spudis makes clear that this is no permanent truth—all of their missions thus far are "dual purpose". In the end, he proposes a new template for space travel and budget allocation—incremental, extensible building blocks that disperse comfortably into NASA's yearly budget, extraction of material and energy from space to run the equipment located there, and only sending "smart," information-dense materials up from Earth. Polar ice on the moon makes this a practical possibility—but it is up to my generation to make it happen.

I found this talk extremely exciting; I am fascinated by space and travel within it. I would love to be one of the technical minds arguing for this template in the future.

Oftentimes when we do things in space, we do it just to prove we can. Take, for example, the space race. We had to beat Russia simply to prove we could. Mr. Spudis instead strives to make

breakthroughs in areas relevant to international needs. The moon is important because it is, in his words, close, interesting, and useful. Most of his studying has been about how the moon, with its close proximity to earth, is incredibly useful for transportation, research, and potential habitation in the future. The rocket equation analyzes how difficult it is to bring much in space travel, for 90% of the rocket fuel is used just to transport the rocket itself. To that, Mr. Spudis has studied ways that perhaps the moon can be used as a stepping stone for further travel or other ways that rocket fuel can be used more efficiently.

Though I do not see myself having any sort of space related career, his discussion was very important. Population growth has brought about the thought of expanding throughout the solar system, but Mr. Spudis brought up another valid point which I had never considered. Were there to be some sort of catastrophic collision with earth, mankind could be wiped out if we don't expand past earth. This adds further importance to space expansion. The moon is also an excellent place to start for three reasons. Its close proximity allows safe travel (Apollo 13 wouldn't have survived were it going to Mars), real time data can be collected and transmitted, and data can be quickly obtained because trips to the moon are fairly short. As Dr. Neal said at the end of the presentation, this will be our problem to take care of, so even if I am not directly involved it is important to be aware.

In this seminar, Dr. Paul Spudis of the Lunar and Planetary Institute gave an overview of his ideas regarding the future of space exploration. Compared to the mentality of the Cold War space race, Dr. Spudis offered a different perspective: instead of one-off, use-and-discard instances of space travel, he promoted the development of a sort of "transcontinental railroad" in space. Dr. Spudis suggested using the resources we might find in space - for instance, water on the moon - to further our spacefaring ability by eliminating the need to launch directly from Earth, which takes a massive amount of energy. The goal of our country should be to become "spacefaring," meaning possessing the ability to go where we please and do what we want in space, a bold notion indeed. Dr. Spudis stressed that space is a very useful resource, mainly in terms of the satellites etc. stationed in the cislunar space between Earth and the moon, but there is certainly more to explore beyond simple satellites.

I found Dr. Spudis' lecture quite interesting, even though I don't see myself doing much with space in the future. That cannot be known, however: perhaps fate will have me designing lunar structures. Even if not, I am interested in the direction space travel is taking, and Dr. Spudis' talk gave great insight into a possible trajectory for it.

Although Dr. Spudis's lecture was not strictly speaking Civil Engineering related, his topics and principles discussed have a broad effect upon the future of my career. First off, it is critical for engineers to find a monetary value for every project for a vision to be completed. Furthermore, the vision must always fit into a specified budget and is sometimes better to be incrementally completed. Speaking on lunar infrastructure, future design firms will be contracted out to design and construct the various structures on planets and satellites. Therefore, it is helpful to learn and explore the possibilities related to space travel to be knowledgeable enough to design extraterrestrial structures.

We have economic, scientific, and security interests in space that require a new rationale for exploring, prospering, and securing. The U.S. wants to build up a presence and control in certain spots in cislunar space to have any control on future international policies regarding space, since those who are present make the rules. Ultimately, we need a plan to achieve the goal of being able to go anywhere, for any length of time, for whatever job we have to do. Rather than an air and space view, it is a space-faring view.

Although I am not an Earth Science major, this presentation had huge value to me. Even when dealing with politics as a regular citizen, I will now pay more attention to "space politics" and how politicians view the space program. It is also incredibly important as an environmental engineering major to understand the importance of developing an achievable plan. Before implementing any project, a plan must be thought-out, known to be realistic, and testable. Dr. Spudis has clearly spent the time and effort in figuring out how to make such a plan that can be applied to the hostile environment of space.

This challenges seminar was exciting because it was unique and discussed a topic not emphasized within civil engineering at Notre Dame. It was interesting to hear about the possibilities of development in relation to space. I think it could lead to an interesting discussion about if the United States should spend money on these developments. Since those in charge of a lot of the money are not engineers, it will be up to the engineers to present the benefits in an attractive light. This seminar was helpful in seeing all components of an engineering project, going past the technical work. These types of unique talks should continue, so that students are introduced to topics beyond the typical structural and hydraulic concepts.

The idea that taking moon aggregates and extracting frozen water from the poles to make a base is a very interesting idea that should be looked into. It was also interesting to see the science behind the propellant fuel that would be created for satellite maintenance and travel. This lecture gave me a basic understanding of the satellite ring surrounding the planet, and how engineering could be used to leave the earth and colonize the moon.

Paul Spudis's work called to mind a presentation from Clive Neal, a professor at the University of Notre Dame. His story centered on the first lunar landing, a moment that thence guided his interests and ambitions. Spudis echoed much of what Professor Neal believes regarding the opportunity that exists on the moon, for deep space travel, and economic reasons. He envisions a new economy founded on the resource wealth of the moon, an economy that would drive innovation on Earth, not unlike how NASA changed the communications and transportation technologies of the sixties. We wouldn't have the internet if not for NASA. There is a great amount left to explore beyond our planet, and I have rarely heard an economic reason so eloquently expressed as between these two individuals. While it may not factor directly into my career choices, it has certainly redefined my perspective on the vitality and dynamism of the CEEES fields.

While I am interested in water resources engineering, I hadn’t really considered the possibility of using resources from the moon. It is also interesting to see how government and international issues can be related to engineering, both in a good way and a bad way as it can slow progress. Thinking of having a career that would involve paying close attention to resources from the moon is a little strange, but I like knowing that those possibilities exist and that there are further resources that can benefit humans.

By comparing space to the ocean, I was able to visualize space as another environment and another extension for human resource dependency. As an environmental engineer, maintaining resources and sustaining life is important wherever human interaction exists. Before Dr. Spudis's talk, I had never deemed space as a possible place for environmental engineers to play a role in since there are no lifeforms in space. But, as humans continue to venture further out and as satellite junk and pollution

circulates through our atmosphere, I can see the relevance for a future profession in environmental engineering.

What I believe this lecture can teach me regarding my career interests is that there are multiple ways to present an issue. Most people believe space and lunar missions only have scientific potential and no practical applications. Mr. Spudis has been able to sufficiently prove that this is not the case. As an engineer, I must be able to learn to adapt this method when presenting highly technical concepts to sects of the populace not well-versed in the scientific lingo associated with them. If I can master this skill, then I will have a permanently useful talent that will help me enter politics or be a useful advisor to them.

This brings me to the important lesson I learned. Spudis stressed throughout his presentation that in order for a mission or feat of engineering to be supported, it needed to have practical benefit to people that they can see affecting their lives. To this end, one cannot often design things without a demand for it, and thus it is important to always consider how projects can actually benefit people so that one's vision can come to pass.

Of the lessons I took from this lecture, a major one was concerned with the necessity of one's ability to convey the practical value of something. When presenting an idea to a group of people, such as Congress, they are not impressed by opportunities for science of grand future plans, instead they are concerned with what kind of practical or economic value can come from something. This seminar also was the most interesting and exciting one we have had in this class. As such, this lecture was very inspirational in the sense that I see that I can get involved in some very cool stuff as an engineer that I may have not thought of.

I thought it was really interesting when he said that space exploration is not analogous with flight but rather with sea exploration. The term spacefaring sums this up well. His views on space exploration showed that sometimes you have to reject the established processes in order to achieve on new horizons. As engineers we should be trying to figure out what the new frontier is and think about it uniquely. As Dr. Spudis said, if we are there then we will have a say in it. This could refer to any technological or material advance within civil engineering. Additionally, I liked what he said about needing "early, recurring milestones for major objectives." When you are trying to persuade people to invest completely in your idea, you need small benchmarks to build their confidence over time. This same plan should be used for engineers working with building owners and any other regulatory or funding body.

I found this presentation very appealing. I was always very interested in space growing up and used to love watching the shuttle launches on TV. I was heartbroken when they stopped that program, but would love to see us expand our realms and attempt to maintain a presence in space. I was shocked how little his idea cost as well with respect to fitting within the current budget. I hope that some of his ideas receive backing going forward because going out into space and trying to do something useful makes sense given the eventual limited resources here on earth, the national interests mentioned, as well as it satisfies the natural human urge for curiosity and exploration beyond our own world.