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Engineering Tools of Scientific Discovery in Popular Culture, Part I in a Series of Thematic Courses Introducing Non-Majors to Space Exploration Concepts and Topics

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Engineering Tools of Scientific Discovery in Popular Culture, Part I in a Series of Thematic Courses Introducing Non-Majors to Space Exploration Concepts and Topics

The University of Denver (DU) has a Common Curriculum which provides students with a well-rounded education by creating a context for major or minor courses of study and introduces students to new areas of interest. One of the main elements of the common curriculum is a series of elective courses which cover "Scientific Inquiry: The Natural and Physical World" (SI-NPW). If a student is not an engineering or science major, they must choose one of these series while attending DU. Most of these electives are given by the School of Natural Science and Mathematics (NSM), but one series of courses was offered by the Ritchie School of Engineering and Computer Science (RSECS). This paper describes the first course of a three-part series of courses that was developed within RSECS to expose non-majors to aerospace engineering and space topics. This first course was named "Exploring Engineering Tools of Scientific Discovery (Engineering SciD) in Popular Culture". In this case, the "Popular Culture" was the movie "The Martian", and "The Exploring Engineering Tools of Scientific Discovery" was the tools of space exploration that lead us to learn more about our solar systems and corresponded to the National Academy of Engineering Grand Challenge title, "Engineering Tools of Scientific Discovery". At the time this series was created, RSECS was becoming a National Academy of Engineering Grand Challenge Scholars Program (NAE GCSP) school and incorporated that theme into new course offerings. Simultaneously, the school was also becoming part of the Kern Entrepreneurial Engineering Network (KEEN), and we incorporated many elements of KEEN into the sequence of courses which stress the Entrepreneurial Mindset and the three C's, Curiosity, Connections, and Creating Value. Through a series of student surveys during the inaugural years of this course, it was clear that the methods and pedagogies used in this thematic course created an environment for non-major students to thrive and become curious about aerospace engineering and space topics. This paper describes several of the methods used to deliver the content to non-majors, reflections on the course's success and failures, and results of student surveys that also indicate areas of success and failure.

Introduction

One of the main elements of the common curriculum at the University of Denver (DU) is a series of elective courses which cover "Scientific Inquiry: The Natural and Physical World" (SI-NPW). If a student is not an engineering or science major, they must choose one series while attending DU. Many of these electives are given by the School of Natural Science and Mathematics (NSM), but one series of courses was offered by the Ritchie School of Engineering and Computer Science (RSECS). This paper describes the first course of a three-part series of courses that was developed for the 2017/2018 school year by RSECS. At the time this series was created the school was also becoming a National Academy of Engineering Grand Challenge Scholars Program (NAE GCSP) school [1] as well. There are 14 NAE Grand Challenges, and though this course is for non-majors, we decided to develop it around one of the NAE Grand Challenges, "Engineer the Tools of Scientific Discovery". Simultaneously, RSECS also was applying to be part of the Kern Entrepreneurial Engineering Network (KEEN), and we incorporated many elements of KEEN into the sequence of courses which stress entrepreneurial minded learning (EML), and the three C's, Curiosity, Connections, and Creating Vale (3C's) [2].

A committee convened in 2016/2017 to strategize what the new RSECS SI-NPW offering might become. As the committee was reviewing the 14 NAE Grand Challenges on the NAE website [3], the "Engineer the Tools of Scientific Discovery" was represented by a photo of one of the Mars Exploration Rovers (Figure 1). Having just created a project for my "Introduction Aerospace Engineering II" course that explored some of the science and engineering from the novel and movie "The Martian" [4] [5], I mentioned that maybe an entire course could be created around "The Martian" with the Grand Challenge theme. These discussions ultimately led to the creation of a whole new course series based on the Grand Challenges theme starting with the course described in this paper. The first course was named "Exploring Engineering Tools of Scientific Discovery (Engineering SciD) in Popular Culture". In this case, the "Popular Culture" is "The Martian", and "The Exploring Engineering Tools of Scientific Discovery" is the tools of space exploration that lead to learning more about Mars and the solar system.

Figure 1. From the National Academy of Engineering Grand Challenge website showing the Mars Exploration Rover under the 14th challenge, "Engineer the Tools of Scientific Discovery" ([3] https://www.engineeringchallenges.org/challenges/discovery.aspx)

Methods

Course Development

In Science, Technology, Engineering, and Mathematics (STEM) curriculum development, Space Exploration can provide a basis for a thematic course which covers many STEM fields. None of the fields are covered in depth, but this coverage is ideal for a non-major student course because this allows exposure to all sorts of fields rather than just simply one field such as physics, mathematics, biology, chemistry, or engineering. In addition, this course could provide a nice introductory course for engineers as it is interdisciplinary in its nature.

One of the main themes incorporated in this course is the concept of "Engineer Tools of Scientific Discovery". For this definition we use the NAE Grand Challenge description:

“In the century ahead, engineers will continue to be partners with scientists in the great quest for understanding many unanswered questions of nature. In the popular mind, scientists and engineers have distinct job descriptions. Scientists explore, experiment, and discover; engineers create, design, and build. But in truth, the distinction is blurry, and engineers participate in the scientific process of discovery in many ways. Grand experiments and missions of exploration always need engineering expertise to design the tools, instruments, and systems that make it possible to acquire new knowledge about the physical and biological worlds.” [6]

One of the main purposes of the SI-NPW electives is to have a series of courses that are built upon each other. For this reason, the outline for three courses were developed simultaneously and each named. The three-part sequence is the following with each having the Grand Challenge theme in the name:

1. Exploring Engineering Tools of Scientific Discovery in Popular Culture (i.e. The Martian)
2. Designing and Building Engineering Tools of Scientific Discovery at the Component Level
3. Designing and Building Engineering Tools of Scientific Discovery through Systems Engineering.

The focus of this paper is the first course, but, briefly, the second and third course introduce non-majors to engineering design through designing component level prototype apparatus and then finally to systems that accomplish mission level objectives. In these additional two courses students learn computer programming by using the Python programming language to interact with Raspberry Pi hardware implemented at both the component and system level. By analogy the students learn that these mission designs may add to scientific discovery just like a mission to Mars may add to scientific discovery.

The second main theme for the first course is a space journey from Earth to Mars, just like the main character Mark Watney achieves in “The Martian”. The tools of discovery explored are technological innovations like rockets, spacecraft, sensors, rovers, and life-support systems. The discovery is new knowledge acquired from these tools about planets, space, living in space, etc. This first course was thus created to introduce the students to the topics of space exploration from both the scientific and engineering perspective while looking at instances of space exploration in popular culture. Additional popular culture excerpts included during the first course are from popular culture movies like, “Gravity” [7], “Sunshine” [8], “The Right Stuff” [9], “Hidden Figures” [10], and “October Sky” [11], but focused primarily on “The Martian” and the Mars exploration theme.

This course was developed for three hours of lecture (50-minute class periods) per week and 2 hours of associated labs weekly for 10 weeks on a quarter system. The technical content that is covered in this course is from the textbook “Understanding Space” [12]. “The Martian” [4] and supplemental slides sets cover the range of topics related to missions to Mars for this course. The sequence of topics is shown Table 1.

Table 1. Topics and labs covered in EngSciD

Topic	Lectures (3 x 1 hr)	Labs (2 hrs weekly)
1	Introduction to the Course Series, What is Space?	Lab Viewing of "The Martian"
2	Rocket Capability and How Rockets Work (Both from Earth and from Mars)	Water Rocket Activity
3	Orbits and Transfer Orbits (Monitoring Mars or Earth, and Getting to Mars)	Software Analysis of Planetary Orbits Mars and Earth
4	Engineering for the Climate of Mars and the Space Environment	Vacuum Chamber Experiment and Environmental Chamber
5	Inhabiting Mars (Shelter Design)	More Vacuum Chamber and Environmental Chamber Experiments
6	Botany/Biology for Sustaining Life on Mars	Growing plants in the Martian soil Experiment (Soil Testing)
7	Communications Between Earth and Mars	Simulation of Communication Modes and Languages
8	Energy Sources for Mars Operations (Solar Cells and Radio Isotope thermoelectric generator (RTG))	Solar Cell Measurements under various conditions (cloud, reduced light, sun angles)
9	Chemistry for Survival	Distillation Experiment
10	Geological Nature and Corresponding Terrain of Mars and Roving on that Terrain	Rover maneuvers in a simulated Martian Environment

The student learning objectives for this course are tied to an overall set of objectives established by the DU SI-NPW committee. The objectives then are tailored to be more specific to each course, and for this course are the following:

- Apply knowledge of scientific practice to evaluate evidence for scientific claims in popular culture references related to space exploration (i.e. The Martian)
- Demonstrate an understanding of science as an iterative process of knowledge generation with inherit strengths and limitations through weekly activity reports on engineering tools of scientific discovery.
- Demonstrate skills for using and interpreting qualitative and quantitative information through laboratory exercises related to the engineering tools of scientific discovery.

Description of Lectures and Labs

The class was developed to target the first four levels of Bloom's taxonomy, remember, understand, apply, and analyze [13] by using the ten topics given in Table 1. Reaching the highest orders of Bloom's taxonomy, evaluate and create, is left to the final two courses. The lectures are traditional class presentations with a set of multimedia slides that introduce the students to each topic. My method in class is to use the Socratic method, when possible, such that the students are asked to answer thought-provoking questions. "The Martian" is then used as a vehicle to introduce real science and engineering topics to students with the adage "Bring Him Home" [4] as the theme of the course. In addition, the laboratory activities create an Experiential Learning environment to reinforce the concepts.

Overview of Space Science

The first topic discussed is space and space exploration. Mark Watney is out in space exploring our solar system, so "What is Space?". In the process, definitions of space are discussed and why human civilization may want to go to space. The students become curious (one of the 3C's) by viewing the movie, "The Martian", during the first lab section. Excerpts from the novel which have more detailed explanations of science and engineering are used throughout the course along with replaying some clips related to each relevant topic.

Rockets and Launch Vehicles

Then, once the reasons for going to space are established, the first critical technology that enables spaces exploration is rockets. In class, several examples of rockets are introduced which are connected (one of the 3C's) back to the Mars Ascent Vehicle (MAV) which Mark Watney uses to finally escape Mars. In the associated laboratory, students build water rockets and launch them exploring variables like number of fins for stability, pressurization of the water, and mass ratios (fuel to vehicle mass) that give the longest flights (Figure 2). The students are then asked to write a summary paper on their findings and offer what they think is the best design for water rockets and connect (one of the 3C's) those concepts back to real rockets.

Figure 2. Water rocket launched from safe distance during lab with a launcher.

Orbits

The next topic explored is spacecraft orbits. First, Kepler's and Newton's laws are introduced to give some mathematical rigor so that a few simple two-dimensional orbits can be described. The students learn about elliptical orbits, circular orbits, parabolic orbits, and ultimately about how hyperbolic orbits may provide the escape velocity that will allow a space vehicle to get to Mars to rescue Mark Watney. Simple spacecraft maneuvers connected (one of the 3C's) to getting Mark Watney the last kilometer or so to the fictional Iris Orbital vehicle are taught as well as the Hohmann Interplanetary Transfer connected to getting supplies from Earth to Mars. In the labs, the students use a software tool called, "Orbits", that allows them to input Classic Keplerian elements describing certain Earth-based orbits and then have the software trace out the Orbits (Figure 3). The students proceed to make connections (one of the 3C's) between the trajectory of the orbit and the ground trace, identifying potential missions that each orbit may undertake.

Figure 3. Students learning to use the Orbits program in a lab section

Space Environment

The next three lectures were on the space environment and the Mars environment. In these lectures, the harshness and characteristics of space are described: particle and solar radiation, harsh thermal environment, weightlessness/reduced gravity, vacuum, and space debris. Based on the above lectures the students become curious (one of the 3C's) about how a spacecraft or human may interact with this environment in space on the way to Mars: "How should we design for this environment such that the spacecraft and the humans survive?". The two associated labs for this section are a tabletop vacuum chamber and a cold chamber with dry ice and fans which provide temperatures as low as -40 °C (Figure 4). The students explore vacuum effects on water balloons, sound waves, and plant tissue. They also explore extreme cold on electronics (LED screens) and plant tissue. They are asked to connect (one of the 3C's) these laboratory effects to the space environment in a summary paper.

Figure 4. Environmental chamber testing

Inhabiting Mars

At the end of the journey, astronauts land on Mars after traversing space, and the Mars environment is compared with the space environment and Earth environment. The students learn that, in many ways, the Mars Environment is more like the space environment. The class discusses whether the assumption that Mars could serve as a "lifeboat" if Earth becomes uninhabitable is reasonable. In this section there are discussions about the minimum resources that would be needed for maintaining a colony on Mars. The basics of food and shelter are discussed first. This lecture material is then connected (one of the 3C's) back to Mark Watney's shelter issues and food issues for his longer than expected stay on Mars. The lectures cover cultivating crops on Mars in controlled environments and methods for adapting soil and water to support crop growth. The current scientific experiments at the International Space Station on growing plants efficiently in space are discussed [14]. The literature that indicates that potatoes (a Mark Watney staple) is reviewed [15], revealing that many of the ideas in "The Martian" are reasonable. For a lab activity the students do soil testing of four soils to indicate the viability of the soils for crop growth. They do a pH, N-P-K test of the soils and then determine which of the four soils are likely to be the best candidates for growing crops.

Communications

A major plot element of the movie "The Martian" is Mark Watney re-establishing communication with NASA after being left behind on Mars. In this unit, ways of communicating with Mars are connected (one of the 3 C's) to Mark's predicament. Students learn how the different Martian probes (including Pathfinder which is highlighted in the movie) communicate with Earth and how long it takes for a signal to reach Earth. The different communication methods used with Low Earth Orbit (LEO) satellites are studied as well as how the Deep Space Network is used in Martain communications. Analog and digital signals are discussed in lecture along with the type of antennas and power needed for signal transmission. In the complimentary lab exercise students attach various signal generators to an oscilloscope and determine what type of signal is being produced, analog or digital. In addition, the students investigate transmitting signals wirelessly using an Infrared (IR) light emitting diode (LED) transmitter and receiving the signal with a light sensor. They vary the distance and angle to determine how the strength of the signal changes with distance. To facilitate making these communication devices easily, LittleBits ® were used for a quick assembly (Figure 5).

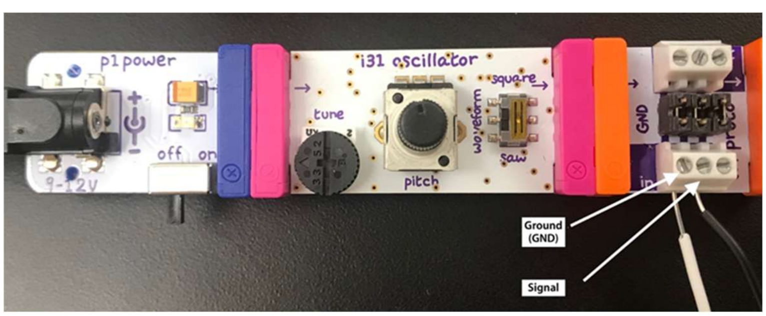

Figure 5. LittleBits used for communications concepts

Energy for Mars/Space

For this topic, the long-term energy need for establishing a colony on Mars along with viable options are discussed. In these lectures, fossil fuels and wind energy are ruled out as unlikely energy sources on Mars. Though Mars is windy the low density of the atmosphere does not translate to a lot of wind energy until the winds are very high. Likewise, Mars does not have the geological history of Earth to create carbon-based fossil fuels. The lectures then cover the solar resource, solar technologies, and nuclear energy technologies. How the solar resource would differ between Earth and Mars is shown with equations and conceptually discussed. Potential nuclear fuel sources and how reactors might aid the first Mars colonies are also discussed. The energy needs are connected (one of the 3C's) to the examples in "The Martian". Mark uses the "Hab" solar panels to get to the Ares site and unburies a Radio Isotope Thermoelectric Generator (RTG) for a heat source. In the associated laboratory exercise, the students investigate the energy output of a solar panel by measuring current and voltage while the panel is subjected to different angles during the hours the sun is shining for their lab time. They also simulate a dusty solar panel by placing an evenly wired mesh over the panel. Lastly, they measure how well the solar panel can power a variable speed DC motor by counting the number of motor rotations for a given minute.

Figure 6. Solar panel experiments

Chemistry for Survival on Mars

The main chemistry that Mark Watney uses to survive is to convert the rocket fuel Hydrazine and CO_2 from the Martian atmosphere to large amounts of water for growing his potato crops. In the lectures on this topic, the students explore the chemical reactions for that process and connect (one of the 3C's) it to the movie. Additional chemical reactions that might more easily sustain a Mars colony are then discussed in class. The most interesting reactions involve using the resources already available on Mars: ways of making rocket fuel, ways of making steel, ways of using photosynthesis to create breathable environments, and ways of using and/or distilling the already available water under the Martian surface. These reactions create additional curiosity (one of the 3C's) about how the resources on Mars might be used. The simplest complimentary lab exercise is then to distill water from an unpure source [16]. In this case the students distilled

Cherry Coke into three fractions, cherry aroma, phosphoric acid, and water. They tested the pH of each of these components. The apparatus is shown in Figure 7.

Figure 7. Distillation apparatus.

Geology of Mars and Terrestrial Planets

This topic covered the geology of Mars from the interior to surface. Throughout "The Martian", various geologic features are discussed and in the first and final scenes in the movie geological activity plays a crucial role. In the first scene, a dust and sandstorm are what strand "The Martian", and in the closing scenes Mark outruns another dust storm while traversing some amazing geological features to get to the Ares site.

In the discussion, the geology of Mars is compared to the other terrestrial planets in the solar system and to the Earth's moon. The students discover why the surface of Mars looks like it does currently and why the planet is considered "nearly dead" in geological terms. One major implication that is discussed is the lack of a magnetosphere to protect the planet from incoming solar radiation due to a relatively non-active interior due to lack of a liquid outer core. On the other hand, the surface of the planet shows past activity of tectonics, volcanism and water flow with the main two surface erosion features currently occurring due to impact cratering and wind erosion. Climate change on Mars is discussed as to how that has led to a planet with a very different atmosphere and no associated surface water. Several of these topics connect (one of the 3Cs) to the environment Mark encountered.

The associated lab activity for this topic was "Rover Maneuvers in a Simulated Martian Environment". This activity is loosely related to geology and is meant to correlate to maneuvers by a rover on Mars traversing geological obstacles. In this case, the students were given an obstacle course that they needed to navigate in the lab with a remote-controlled car. However, the student controlling the car could not see the course, but another student was allowed to give them commands in terms of analog-like data commands trying to get the rover to waypoints and then to a destination. Using this information, the students programmed a "Mission Plan" and tried to get their Rover around obstacles to the way points and the destination.

Results and Assessment

This course was taught during the 2017/2018 and the 2018/2019 academic year. The course was not initially tagged in the DU course database as an SI-NPW course, so students signed up in Fall rather than Spring for the Fall course. However, this late enrollment worked out well as we were able to prototype the course for the first year with 25 students rather than having the typical 75 to 100 students. The second year, we set the enrolment limit as 75 students and had 76 students initially enrolled. The typical student majors enrolled in these courses were business, computer science, and music majors. Students were assessed the first year using weekly problems sets, daily questions, and lab reports, and peer reviews for group lab work. In the second year, we continued to use these same assessment techniques but also included a Midterm and a Final Examination.

In the first year, the students provided us a midterm course evaluation, so that we could see how the course was going from their perspective. A Table of some basic questions that were asked is shown in Table 2. The students' written feedback was provided approximately near Topic 4 on the Space Environment.

Table 2. Series of questions to gage student interest in STEM and interest in the current course.

1. On a scale of 1-10, (10 being the highest, 5 Neutral, 1 being the lowest) rate your interest in the general fields of Science, Technology, Engineering, and Mathematics (STEM).
2. What have you liked most about this course so far?
3. What have you liked least about the course so far?
4. Is there anything that has surprised or amazed you within the topics in this class?
5. Of the topics still ahead, are there any in particular that interest you more than others or that you are looking forward to?

21 of 25 enrolled students responded to the series of questions. On Question 1**, the average interest in STEM was 7.50 with a standard deviation of 1.40.** Three students went out of their way to indicate that their rating was higher for Engineering and Technology and lower for Science and Math (i.e. 10 for Engineering and Technology and 5 for Science and Math, 8 for Engineering and Technology and 5 for Science and Math, and one mentioned a 7 for Engineering and Math, but a 6 for Science). The results to Question 2 and 3 were categorized as shown in Table 3. Student responses were categorized to the best of our ability, noting that at times students gave more than one response to what they "Liked Most", while some also claimed that there was nothing they "Liked Least".

Table 3. Frequency of answers to Question 2 and Question 3.

Categories: Liked Most	**Number**
Related Lab Exercises	9
Water Rocket Lab	4
Lecture: Professor, Class Atmosphere, Examples, Slides	4
Connection to "The Martian"	3
Space Concepts in General	3
Vacuum Chamber Lab	2
Orbit Topic	1
History of Space Technology	1
Categories: Liked Least	**Number**
Math (Equations/Formulas)	9
Orbits Lab	2
Weekly Assignment	2
Professor Speaking Rate	1
Labs not Rigorous	1
Clarity of Pre-Lab Expectation	1

Some typical quotes from Question 2 were the following:

"The labs have been much more interesting; and, therefore fun to participate in than previous science courses I have taken."

"Labs are a blast…Topics are fascinating…Professors are enthusiastic."

"I love that you have made Rocket Science and this type of class accessible to non-STEM majors. Also love the labs we have had, they are a blast."

"The Labs. Lots of fun opportunities to play with science stuff."

"I loved learning about space. It's a completely new topic to me."

"All things about space have been really cool."

Some typical quotes from Question 3 were the following:

"Too many equations…"

"The part of the class I like the least are the equations."

"The equation problems have been difficult sometimes."

"The mathematical equations on the weekly questions have been very difficult for someone with little to no science experience at this level."

"Sometimes the professor talks a little bit too fast to follow."

For Question 4, the students indicated that they were amazed or surprised in the following main categories: rockets, orbits, space environment, and the connections to scenes in “The Martian”. In the rocket category, the main knowledge that was surprising or amazing was that most Earth atmosphere propulsions systems need air and thus do not work in space. They were also impressed with how well the water rockets they built were able to fly. For the orbits category, some main recurring themes were that it was amazing how fast low Earth satellite orbits are traveling (7.8 km/s), and how that there is still gravity in space orbits, but the centripetal and gravity forces balance to give a “zero gravity” environment. In addition, a few students mentioned that they were amazed by all the different missions that satellites do based on where their orbits are placed.

For Question 5, the most common topic that students were looking forward to in future lectures were items relating to Inhabiting Mars including the Martian environment; Geology of Mars; and ability to grow plants and survive on Mars. Most of their future interests were about Mars and how those topics connected to the movie, “The Martian”. A few of the students mentioned that they were already truly excited to get to the third quarter in which they would build a “Satellite”.

The final assessment by students were the university administered course evaluations which are given at the end of the course. To gauge course success from the students’ point of view, DU administers a questionnaire to students on 14 different questions in which the course and instructor attributes are rated on a scale of 1 to 6 (1 = Strongly Disagree, 2 = Disagree, 3 = Disagree More, 4 = Agree More, 5 = Agree, 6 = Strongly Agree). Out of 14 questions, the five most pertinent statements for evaluating the success of the course are given in Table 4 along with the results. 22 of 25 students responded to provide these course evaluations.

Table 4. Student course evaluations.

Text for Student Response	**Score (out of 6)**
“I learned a great deal from this course”	5.41
“Over all this is an excellent course”	5.19
“The teaching methods and learning experience were appropriate for my needs”	5.41
“The instructor fostered a classroom climate of respect and participation"	5.45
“Over all this is an effective instructor”.	5.50

Students are also given the opportunity to comment on three questions on the course evaluations related to what they thought were strengths and effective teaching methods. The comments on the final questionnaire echo what was seen from the earlier class survey. On this course evaluation survey, there were two questions that addressed the methods that were used for this course. The questions with some of the responses are listed below.

Question: What were the strengths of the course?

"[The Professor] has such a great attitude and a contagious energy. It's so much easier to love a course when the professor is passionate and excited about the material. The labs were fun and I constantly felt like I was learning new things."

"10/10 the professor was fantastic, passionate, approachable, fair and very adaptable/ understanding to/of the class environment. - I loved the diversity in the topics. What made this class a joy to go to was that every week it was different. - I truly appreciated the timely news and up to date knowledge on the subject matter. Rather than sticking with the theories developed in the 1800's and 1900's the professor kept it relevant with news from space ex and more recent experiments."

"[The Professor] was always very excited and he knew the material. He knew how to explain every concept in ways that we would understand. The labs that went along with this course were also really helpful."

"Great examples, love the content, very interesting"

"Great media presentations, interesting lectures, entertaining experiments"

Question: What teaching methods most effectively facilitated your learning in this class? e.g., assignments, class interaction, lectures, final paper or project, media presentations, group project or exercise, readings and/or text, etc.

"I liked the lectures because they were always taught in an interesting and a fun way. I never got bored in that class considering that it is lecture based."

"[The Professor] gave great lectures that were highly informative. Daily questions helped to assure we were understanding the material."

"I loved the real tools we got to use in lab. The little bits, the soil testing and distillation were especially relevant activities. The rocket lab was just fun :). - I liked the movie clips, keeps true to the name of the course and it is a fun example to look at and asses."

"The lectures, assignments, labs, were all great!"

At the end of the series of courses, the students were asked once again some similar questions through electronic surveys and were also given the opportunity to provide feedback on the course evaluations. The results at the end of the three-course sequence will be compared in our final paper.

Discussions

Overall, the first 25 enrolled students were excited about this series of courses. This attitude was generally exhibited by their assessment of the first class. Several of the students were looking forward to the third quarter in which they would build an engineering system to complete a mission but enjoyed the first course as well. The math requirements for the remaining topics were also less than in the first half of the course and might have added to an additional uptick in excitement by the end of the course. There was almost no student mention of equations being bothersome in the final course evaluations. Their final evaluations focused on their enthusiasm for the lecture content and the complimentary laboratory experiments. Experiential Learning was a large part of the course, and based on their comments it was evident that the students valued this type of learning despite the time commitment.

Using popular culture like “The Martian” provided a basis for inspiring the students’ initial curiosity in our course. Likewise, “The Martian” was chosen because there were several aspects of space travel and exploration that were portrayed rather accurately in the novel and film and could be analyzed with simple equations. In addition, the story drama provided some real engineering and scientific challenges that capture students’ attention. Before using this theme for a full course, a prototype project was incubated in an undergraduate aerospace engineering course. In that course, it was well-received among engineering students. When choosing to use popular culture for a course, the above factors should be considered.

Having a Grand Challenge theme to focus on such as “Engineering the Tools of Scientific Discovery” was a great way to relate the information to students. One student mentions that that the Professor “kept it relevant” by using recent experiments and examples from SpaceX. This technique was intentional and allowed the theme to be tied into the course content many times. For instance, we discussed how reusable rockets like those developed by SpaceX could be used to make Mars Missions more plausible because it may reduce costs associated with payloads and weights. In addition, there were several “hot-off-the press” moments about new discoveries about different assets on Mars such as water locations. Then we would discuss what spacecraft helped make the discovery and what instrument was used that made this new discovery possible. In addition, we would take the new information and relate it to “The Martian” and discuss how this information might have affected Mark Watney. These course discussions helped develop more curiosity and connections (two of the 3C’s).

Using the KEEN EML when developing this course also made it more palatable for the students. The 3C’s are Curiosity, Connections, and Creating Value. This first course exemplified both “Connections” and “Curiosity” for our students with the latter course emphasizing “Creating Value” as well. Typical student objectives associated with “Curiosity” are the following: “Students will demonstrate constant curiosity about our changing world” and “Explore contrarian views of accepted solutions” and for Connections: “Integrate information from many sources to gain insight”.

Graded evaluations both on weekly and daily assignments and lab reports indicated that the students in this class predominately attained all the learning objectives set forth by the SI-NPW committee. This conclusion is somewhat informal in that the instructors are basing this assessment on grades attained on all course work rather than one or two assignments that were intentionally designed to exhibit these objectives.

This series of courses went through a second iteration in 2018/2019. I taught the first course in this three-part series in the second year in Fall 2018. In the second year, the student numbers rose to 76 students at initial enrollment. The lecture consisted of 70+ students and the lab sections were capped at 25 students. In the first year, we had prepared lab resources as though we would have 100 students spread throughout five labs, so we were prepared to handle these numbers from an equipment standpoint. However, more students in lectures and labs, as might be expected, diminished the amount of connectivity with students. The labs provided a better place to connect with students as there were two Teaching Assistants, and a professor in most labs. In addition, since this course is one of six campus common curriculum required courses, there were a larger number of international students (approximately 1/3 of the class) in the second year. Some of these students struggled with their English fluency which made scientific nomenclature even harder for them to grasp and posed problems with oral communication with teammates in labs.

As in the previous year, some of the students were math averse, and general algebra was used, but kept at a minimum. To accommodate this many students more course content assessment was done electronically through Canvas® quizzes, exams, and weekly questions that were auto graded. However, the exams and quizzes allowed a more thorough assessment of students' scientific understanding.

Ultimately this course went through a full second year and then RSECS did not offer this course in Fall 2019 due to a lack of faculty availability. The department course loads needed to maintain our own engineering majors made it difficult to sustain a non-majors elective. However, through this experience several of the faculty are excited about using this course as a potential introduction to engineering course for our own students, and thus, some elements persist in the curriculum.

Conclusions

Using these pedagogical methods, KEEN Entrepreneurial Mindset Learning, Experiential Learning, and the Grand Challenge Themes, the students in this course were able to attain various levels of the student learning objectives established by the DU SI-NPW committee. Furthermore, the student surveys and course evaluations indicated that non-major students developed an increased interest in aerospace engineering and space topics while achieving the DU SI-NPW objectives with this type of pedagogical delivery.

First, they were able to apply knowledge of scientific practice to evaluate evidence for scientific claims related to space exploration—this demonstration was primarily done by comparing popular culture depictions of space science with the current scientific knowledge for plausibility. They were able to perceive science as an iterative process of knowledge generation with inherit strengths and limitations by discussing "new" scientific discoveries that occurred since the book and movie were released. They discussed how the new discoveries might affect how the authors depicted the struggle to survive on Mars. In addition, they discussed past knowledge about space and Mars that was believed but has since been disproved. These first two SI-NPW objectives also align with the KEEN EML objective of instilling constant curiosity and connections.

In addition, Students applied qualitative and quantitative information in lab exercises to enhance their understanding of space. For instance, they measured typical space environment conditions in a vacuum chamber and conceptually witnessed the implications on a water balloon in which the water boiled and burst the balloon. Likewise, they measured temperatures in a cold chamber and correlated that to its effect on electronics and plant matter. Experiential Learning was a large part of the course, and based on their comments it was evident that the students valued this type of learning despite the time commitment.

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