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Lesson

Exploring the March to Mars Using 3D Print Models

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Abstract

With the increased availability of 3D printers and open databases containing 3D print files, academic institutions are giving more thought into how such technology can be used in the classroom to further student learning. One way that 3D print technology can augment pedagogy occurs when students achieve learning outcomes by exploring models that are difficult to access or more easily discernible in three dimensions. The goals of this lesson are to develop students' knowledge, problem-solving and teamwork skills through an exploration of the Mars Curiosity Rover Mission. Three-dimensional print models are integrated into a classroom jigsaw collaborative activity to promote student engagement and interest in the various components of the mission, as well as to provide multiple modes of learning. The activity was implemented in an interdisciplinary seminar course for non-majors and could be extended to introductory biology and microbiology courses exploring the properties of life and early microorganisms.

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Supporting Materials: S1. March to Mars: Pre-activity teaching materials and S2. March to Mars: Student handout

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Learning Goal(s)

Students will:

- understand the major aspects of the Mars Curiosity Rover mission.
- consider next steps in a future manned mission to Mars.
- use multiple forms of media and technology to solve a problem.
- develop critical thinking skills.
- develop teamwork skills.

Learning Objective(s)

Students will be able to:

- describe the major aspects of the Mars Curiosity Rover missions.
- synthesize information learned from a classroom jigsaw activity on the Mars Curiosity Rover missions.
- work in teams to plan a future manned mission to Mars.
- summarize their reports to the class.

INTRODUCTION

With the goals of understanding the basic requirements for life, humans have been looking to the cosmos for thousands of years, and actively studying them for hundreds. One of the major focuses of this study is Earth's celestial neighbor, Mars, due to its location and numerous similarities to Earth. As of 2018, there have been 45 attempted missions to explore Mars (including flybys, orbiters, and rovers), approximately half of which have had some degree of success, but no manned missions have been attempted (1). In 2011, NASA initiated the Mars Science Laboratory (MSL) mission, which utilized the Curiosity Rover to explore the surface of Mars, with the specific goal of assessing the environment's ability to support microbial life and determine its habitability (1). In doing so, the ability to test critical features that support and suggest the presence of life as we know it were considered in the development of the rover, along with identification of the chosen location for exploration, and the collection and analysis of data. As such, examining the details of this mission, can be relevant and interesting for a variety of courses, from introductory biology and microbiology courses that explore the basic requirements for life, the variety of forms it can take, and the diverse environments in which it can thrive, to upper level astronomy/astrobiology and other courses.

We designed the March to Mars activity to leverage both an established active learning method, the classroom jigsaw, and 3D printing as a technological tool to foster student learning in a first-year experience undergraduate seminar course entitled "Life on Mars?", with a class size of sixteen students. In general, during active learning students learn by doing, making meaning of their knowledge, and taking ownership over the learning process (2,3). Active learning methods have a demonstrated record for improving student performance in science, technology, engineering and mathematics (4). The classroom jigsaw, described by Aronson et al. (5), is an active learning method that specifically involves students developing, sharing and synthesizing knowledge. In a meta-analysis of various active teaching and learning approaches, the jigsaw method was found to have positive significant impacts on student learning, promoting higher achievement as compared to competitive or individual efforts (effect sizes = 0.29 and 0.13 respectively) (6).

We used 3D models in the lesson to give students opportunities to handle and observe physical representations of the Mars Curiosity Rover, Gale Crater landing site, and path of the Curiosity. We accessed the digital files of such models through NASA's 3D print database; we were encouraged by the increased availability of 3D printers at colleges and universities in Makerspaces, libraries and studios (7,8). NASA's insignia, Mars Curiosity Rover, the Gale Crater Landing Site, and the Path of the Curiosity 3D models were highly appropriate for the activity, implemented during an astrobiology unit in the course.

The March to Mars activity, starts with the formation of Home Teams composed of four students who then review the parts of the activity with their instructor. Each Home Team member selects one of four expert topics (Mission to Mars, Mars Curiosity Rover, Gale Crater, or Path of the Curiosity) to investigate further. Individual Home Team members then join the Expert Group designated by their chosen topic. Each Expert Group member is given an appropriate 3D print model and is asked a series of questions to identify relevant features of the model in order to further explore and/or research aspects of their topic. Through this process, each member on the Expert Group develops a body of knowledge around the expert topic. Expert Group members next return to their Home Teams and share what they have learned as well as their respective 3D model. Home Teams synthesize the information and plan the next manned mission to Mars.

Intended Audience

The lesson is intended for either science majors or non-majors; it was taught during a first-year interdisciplinary seminar course entitled "Life on Mars?" at a liberal arts university during an astrobiology unit. The lesson can also be extended to students enrolled in an introductory biology course that examines the properties of living organisms, a microbiology course that discusses early microbial life, and an interdisciplinary astronomy course during a space exploration unit.

Required Learning Time

The lesson takes approximately 100-150 minutes of class time.

Pre-requisite Student Knowledge

Students are not expected to have any pre-requisite knowledge prior to complete the activity.

Pre-requisite Teacher Knowledge

Knowledge of how to use a 3D printer, or having resources to submit 3D print files to an external company such as Shapeways or Kraftwurx, or others currently available for printing, is important for carrying out this lesson. Printing files on an available 3D printer is relatively inexpensive compared to submitting files to a company. Instructors can estimate costs by uploading files to the external company's website. A teaching strategies guide for implementing 3D printing in the classroom is a useful read for instructors printing their own models (9). Instructors should also have a good understanding of the Mars Curiosity Rover mission, including:

- Background knowledge of the goals and history of the Mars Space Laboratory missions,
- The features of the Mars Curiosity Rover and major findings to date, and
- The major landmarks along the Gala Crater traveled by the Rover.

Instructors are encouraged to review NASA's Mars Curiosity resources to review up to date information on the mission (www.nasa.gov/mission_pages/msl/index.html).

SCIENTIFIC TEACHING THEMES

Active learning

The entire March to Mars lesson requires students to actively engage in learning concepts. Students participate in a classroom jigsaw activity in which they collaborate with peers to explore 3D print models in groups, increase their knowledge by obtaining information from online resources, teach their peers what they have learned and synthesize the information to plan the next manned mission to Mars.

Assessment

Instructors and students formatively assess learning by checking in on team progress each day of the activity through pointed questions and by briefly viewing students' notes to make sure that students are meeting learning objectives. Instructors can ask each team to present their ideas for their next manned Mission to Mars, as well as turn in their summary reports for a summative grade.

Inclusive teaching

The classroom jigsaw strategy is inherently inclusive, as all learners have roles and share the responsibility to actively engage in the activity. In completing the activity, students will also become aware of the diverse teams that have led successful space missions. Three dimensional print models are accessible to students with visual impairments, and additional diverse resources are engaged in written, audio, and visual formats.

LESSON PLAN

Pre-Class Preparation

Instructor

Prior to implementing the activity, the instructor should give ample time to print the models including the NASA insignia (https://nasa3d.arc.nasa.gov/detail/nasa-insignia), Mars Curiosity Rover (https://nasa3d.arc.nasa.gov/detail/mars-rover-curiosity), Gale Crater (https://nasa3d.arc.nasa.gov/detail/CuriosityQR), and the Path of the Curiosity (https://nasa3d.arc.nasa.gov/detail/curiosity-path) using a 3D printer. We downloaded relevant NASA model files to an SD (Secure Digital) card, prepared the models for printing using the software Autodesk, and printed using an HP Dremel printer. Each model has a different print time which can be up to several hours. Enough models are printed for each student in their Expert Group. We find it helpful to print the models a few weeks in advance of class and make a few extras. Provided that the models are handled carefully by the students, they can be stored in a box and reused in future classes. The Curiosity Rover can be pre-assembled for the students and glued together with superglue, or students can put together the model in class using the individual components, if time allows. Instructors should be aware that this model is the most complex and fragile, given its multiple components. Figure 1 shows images of three of the models used in the activity. In preparation for class, the instructor can also pre-assign students to their Home Teams (A, B, C, D) in groups of four and subsequently project the teams during the class session. These assignments can be made randomly, or in an intentional way to promote the desired learning environment, such as by employing student asset mapping prior to the team formation to guide the instructor's assignments (10). Depending on the specific course goals, it may be beneficial to introduce students to some basic information about Mars and human history of exploration prior to implementing the jigsaw activity. Possible content and strategies for implementation are provided in the Pre-Activity Teaching Materials (Supporting File S1: March to Mars: Pre-activity Teaching Materials).

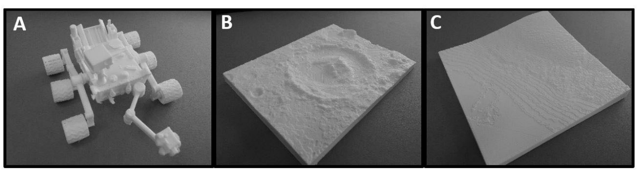

Figure 1. 3D print models utilized in the March to Mars activity. (A) The Curiosity Rover. (B) The Gale Crater. (C) The path of the Curiosity Rover.

Students

Prior to class students view a video highlighting major missions to Mars. A recommended 4-minute video is NASA's 50 Years of Mars Exploration (https://www.youtube.com/watch?v=pwipxdQ74pU). Given that many of the individuals featured and involved in the missions were men, instructors can use the video clip as an opportunistic time to discuss the importance of diverse teams and the steps that are being taken by NASA and other organizations around diversity and inclusion (https://www.sciencemag.org/news/2017/05/women-make-just-15-nasa-s-planetary-mission-science-teams-here-s-how-agency-trying). Students may also be asked to view the historical landing of the Curiosity prior to class (https://www.youtube.com/watch?v=oNviFQpRvwQ). Students should also bring a laptop with WIFI capability to class in order to access online resources.

In-Class Lecture Script

Instructor

At the beginning of class, the instructor provides a brief introduction to the Mars Science Laboratory mission featuring the Curiosity Rover. The instructor can show a video clip of the historical landing of the Curiosity (https://www.youtube.com/watch?v=oNviFQpRvwQ) if the students have not been given it to preview prior to class as described above. The Student Handout (Supporting File S2: March to Mars: Student Handout) is then distributed and the instructor describes the classroom jigsaw activity, the goals of the activity, and the expectations of the students. The Answer Key for the Student Handout is available for instructors by contacting the co-author Derek Dube (ddube@usj.edu). Time should be allowed to answer any student questions about the process prior to proceeding. In our experience, allotting approximately 10 minutes for the introduction of the activity and the process was sufficient. Students then join their Home Team A, B, C, or D. In these groups, students select one of four topics on which to develop expertise (Mission Overview, Building the Curiosity Mars Rover, Gale Crater Landing Site, and The Path Forward). They next join their Expert Groups and observe physical 3D print models and web resources to learn more about their topic. They rejoin their Home Team to share their knowledge which they synthesize by planning their own manned mission to Mars. At the end of the activity, the instructor facilitates whole-class discussion inviting groups to share their ideas. If desired, the instructor can choose, or the class can vote on which manned mission to support. The expected time allotment for implementation of this exercise is 100-150 minutes, and the activity can be conducted over two or three, 50-minute class sessions (see Table 1 for more information).

Students

Students start working towards the learning objective of being able to describe the major aspects of the Mars Curiosity Rover missions through the pre-class assignment and introduction to space missions to Mars given by the instructor at the beginning of class. Students gather in pre-assigned Home Teams and review the directions for how to complete the classroom jigsaw activity with their instructor as described in the Student Handout (Supporting File S2: March to Mars: Student Handout). In their groups, students next choose one of four topics to investigate further, including the Mission Overview, Building the Curiosity Mars Rover, Gale Crater Landing Site and The Path Forward. They join their Expert Teams, interact with the 3D models and complete the activities and questions described in the Student Handout. After working with their Expert Teams, they are expected to be able to describe their area of focus in depth. Students return to their Home Teams and each summarize in 2 to 3 minutes what they learned in their Expert Groups, referring to their 3D print models as appropriate. One group member serves as a scribe and summarizes the major points in 1 to 2 paragraphs on the appropriate area of the Student Handout (Supporting File S2: March to Mars: Student Handout). Afterwards, student groups decide on a plan for the next manned mission to Mars, and detail this on page 7 of the Student Handout (Supporting File S2: March to Mars: Student Handout). They choose a spokesperson to give a 5-minute overview to the class (see Table 2 for more information).

Concurrent and Post-Implementation Assessment

The activity provides numerous opportunities for both informal and formal assessment of student work, affording the instructor the ability to choose those thought to be the most appropriate. During the activity itself, the instructor can ask questions of the students and observe their engagement and note-taking to produce individualized participation grades. The notes can be submitted by the students at the end of the activity to be graded. Additionally, group-based grades can be earned through the written work within the Student Handout (Supporting File S2: March to Mars: Student Handout), including the MSL Mission Report and Manned Mission Plan. Finally, the in-class oral presentation given by each group may be graded either holistically or utilizing an appropriate rubric, as desired. In a previous implementation, we had the students of the class vote on which Manned Mission Plan to "support," and the group selected received a bonus on their written submissions (Note: this was done in lieu of the instructor grading the oral presentations). Depending on the structure of the course, the grades from this lesson could represent a significant portion of the overall course grade, or if many such activities are employed throughout the semester, a smaller percentage.

TEACHING DISCUSSION

During the implementation of this activity, students engaged with both the models and each other in a productive manner. Expert Groups reviewed and discussed websites and online videos. Students examined and appropriately labelled 3D models. Students taught one another in their Home Teams and worked collaboratively to synthesize their knowledge, evaluate the information, and formulate an agreed upon solution to the problem presented. Students commonly presented and discussed multiple options before arriving at any one decision. In the end, the proposals produced by the Home Teams were well-reasoned and demonstrated an understanding of the material and the ability to critically apply that material in accomplishing the tasks. Students utilized specific information during their Expert Group explorations and described detailed decision-making process for each of the required aspects of the mission proposal. In their Home Teams, members from different Expert Groups discussed what they learned about preparing for the mission and the tests and sampling being conducted. Expert Groups also considered the recent findings pointing to evidence of past water in the Gale Crater location, that suggest that Mars could have been potentially habitable at some point in time. Home Teams engaged in active debates over which particular location the Curiosity explored might be of the most interest for further exploration by a manned-mission, with some students suggesting that there may still be life or evidence of past life in the area below the surface. Given that this activity may have been beyond the typical classroom learning experience of some students, the instructor was readily available to answer questions and provide necessary support. Informal feedback suggested that students found the activity enjoyable, interesting, and a positive learning experience in multiple realms.

The activity can be adapted to larger class sizes, to classes where instructors lack access to 3D printers, as well as science courses where instructors desire to explore specific scientific concepts on a deeper level. In larger classes, one physical 3D model can be printed out per Expert Group to reduce printing time. Multiple groups can explore the same topic, essentially replicating the Expert Groups, or multiple students from a Home Team can be sent to each Expert Group. In lieu of the physical 3D print models, students can also view online 3D models on NASA's 3D Resources website. The activity can also be designed such that students revise existing NASA 3D print model files or create their own 3D print models (9). Concepts such as the properties of life and early microbial life can be emphasized in appropriate courses by having Expert Groups focus more heavily on related findings in the Mars Rover missions.

Further, The March to Mars lesson was part of an interdisciplinary course that asked students to consider their personal definition of what it means to be human by examining various topics in biology (e.g. living versus non-living entities), history (e.g. the Cold War), the arts (e.g. the music of David Bowie, science fiction literature/film), political science (e.g. federal financial policies), and aspects of astronomy (e.g. our history of space exploration, astrobiology, astrophysics). The course topics can appeal to students with diverse disciplinary interests. The lesson followed discussions and activities on the history of human space exploration that led to Mars as a planet of interest. After the lesson, students explored astrobiology and viewed the film 2015 "The Martian," both of which were retrospectively connected back to the activity. The film allowed students to visualize a fictionalized version of the manned-mission that they created in the activity itself and deepen their understanding of how Mars in particular fits into the greater context of the human search for truth and understanding.

SUPPORTING MATERIALS

- S1. March to Mars: Pre-activity Teaching Materials (Optional). Notes summarizing major ideas the instructor can discuss on Mars prior to or when introducing the classroom jigsaw.
- S2. March to Mars: Student Handout. Detailed student instructions on the March to Mars activity.

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Table 1. March to Mars - Teaching Timeline

Activity	Description	Time	Notes
Preparation for Class			
Print 3D models a few weeks before class	• Download all model .stl files for printing to an SD card. • Prepare files for printing using Autodesk software. • Print models using a 3D printer over several days. Enough models will be needed for each student in their Expert Group to have one. • Alternatively, submit model files to be printed by a company.	1 week	See Supporting Materials for links to NASA 3D print model files
Pre-assign students to home teams	Pre-assign students to a home team of four students.	10 minutes	
Pre-assign homework	Assign students the video *50 Years of Mars Exploration* to view prior to class.	4 minutes	See Supporting Materials for video link.
Class Activities (May be divided over two sessions)			
Introduction to Missions to Mars	1. Introduce students to the major missions to Mars. 2. Show a portion of the NASA video on the historical landing of the Curiosity Rover.	10 minutes	See Supporting Materials for video link.
Home Team Discussions	1. Project Home Team assignments to the class and have students gather with their teams. 2. Review the procedure for the classroom jigsaw activity with the students. 3. Have students select one of four expert groups to join (Mission Overview, Building the Curiosity Mars Rover, Gale Crater Landing Site, and The Path Forward).	10 minutes	Pass out Student Handout (See Supporting Materials)
Expert Group Discussions	1. Have students join their Expert Groups in assigned areas of the classroom. 2. Pass out 3D print models as appropriate for each Expert Group, 1 for each student. 3. Students use the 3D models and web resources to develop expertise on their assigned topic and answer the questions provided. 4. Walk around to Expert Groups and ask them to summarize what they have learned about their topic.	30-50 minutes	
Home Team Discussions	1. Students synthesize information gathered and develop group expertise to plan the next manned mission to Mars. 2. Walk around to home teams and ask them their developing plans for their next manned mission to Mars.	30-50 minutes	
Wrap-up	1. Ask for a few volunteer groups to describe their missions. 2. Have the class vote on one top mission. 3. Collect assignments.	20-30 minutes	

Table 2. March to Mars - Student Learning Timeline

Activity	Description	Learning Objective(s)
Pre-Assignment	Students watch the video *50 Years of Mars Exploration* prior to class to develop an understanding of the historical context of Mars space missions.	Students will be able to describe the major aspects of the Mars Curiosity Rover missions.
Introduction to Missions to Mars	Students learn about the major missions to Mars and watch the historical landing of the Curiosity Rover.	Students will be able to describe the major aspects of the Mars Curiosity Rover missions.
Home Team Discussions	Students gather in their assigned Home Teams and review the procedure of the classroom activity with their instructor, using the Student Handout. Each student in the Home Team chooses one of four Expert Groups to join to explore a topic more deeply (Mission Overview, Building the Curiosity Mars Rover, Gale Crater Landing Site, and The Path Forward).	Students will be able to describe the major aspects of the Mars Curiosity Rover missions.
Expert Group Discussions	Students next join their Expert Groups in designated areas of the classroom, explore 3D print models as well as develop expertise on their individual topics answering questions provided on Supporting File S8: March to Mars: Student Handout.	Students will be able to describe the major aspects of the Mars Curiosity Rover missions.
Home Team Discussions	Students return to their Home Teams and each share for 2-3 minutes what they learned in their Expert Groups. One person serves as a scribe as the group summarizes what each member learned in 1 – 2 paragraphs (see "The MSL Mission Report" on Supporting File S8: March to Mars: Student Handout). As a group, students use the synthesized information to plan the next manned mission to Mars. They do so by specifying their mission goals, landing site, base camp site, what studies they will conduct, where they will sample or explore further, what they expect to find and the impact for human colonization (See "The Manned Mission Plan" on Supporting File S8: March to Mars: Student Handout).	Students will be able to synthesize their knowledge of the Mars Curiosity Rover missions. Students will be able to work in teams to plan a future manned mission to Mars.
Wrap-up	A spokesperson from each group gives a 5-minute overview of their missions to the class. The class votes on top mission and hands in their assignments to be graded.	Students will be able to summarize their reports to the class.