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Mission MARIJN: a case study on improving undergraduate aerospace engineering education

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Abstract

The TU Delft first-year aerospace engineering course, "Design and Construction," aims to bridge theoretical knowledge with practical application through challenge-based learning. Involving 400 students across 40 teams, the course integrates concepts from mechanics, materials science, and engineering drawing into realistic design projects. The first project tasks students with designing a Rocker-Bogie suspension system for a Mars rover. To enhance student engagement and understanding, a complementary activity called Mission MARIJN was introduced in the 2023-2024 academic year. Mission MARIJN includes three immersive hands-on activities: a remote-controlled 1:4 scale model of the Perseverance rover, an educational exhibit on Martian terrain, and a virtual reality experience featuring previous Mars rovers. Grounded in instructional design principles such as guided inquiry and experiential learning, these activities deepen students' grasp of design requirements and mechanical systems. Survey results from participating students indicate positive learning outcomes, with particular success in the VR and rover modelling segments. This paper presents the design, implementation, and impact of Mission MARIJN as a replicable model for enhancing engineering education through interactive, context-driven learning experiences.

Keywords: Instructional Design, Virtual Reality, Design Requirements, Challenge-Based Learning

1. Introduction

In the first year of aerospace engineering education, students need to be introduced to a wide range of fundamental concepts that will form the basis for their specialized knowledge in later years. However, while acquiring a strong theoretical foundation is essential, there is a risk that a curriculum solely focused on theory may hinder students' ability to apply theoretical concepts to real-world engineering challenges.

To address this concern, the TU Delft aerospace engineering program includes the course "Design and Construction (AE1222-I)" in its first-year curriculum. This course is specifically designed to bridge the gap between theoretical knowledge and practical application, teaching students to integrate concepts from mechanics, materials science, and engineering drawing within a series of challenging and realistic aerospace engineering design projects. In the first of these projects, the students are tasked with the design of a Rocker-Bogie, the suspension system of a Mars rover.

To effectively introduce the course and the initial design project, an introductory activity has been developed, named "Mission MARIJN" (Mars Adventures: Research Initiative for Journey and Navigation). This activity was designed to immerse students in the Martian exploration context. The underlying assumption was that this contextual focus enhances students' appreciation of the practical applications of their acquired theoretical knowledge, which is the central goal of the course.

To develop the introductory activity, one of the instructors of the "Design and Construction (AE1222-I)" course, who is also the main author of this paper, collaborated with TU Delft's Programme of Innovation in Mechanics Education (PRIMECH) [1] .Through PRIMECH's "Accelerate" initiative, additional support was provided for both the instructional and graphic design aspects of the activity, ensuring a well-rounded and engaging educational experience for the students.

This paper presents the Mission MARIJN activity, detailing its specifications, implementation logistics, and student outcomes. The intent is to offer a replicable model for other educators teaching first year aerospace students, or to serve as an inspiration for those teaching similar engineering courses.

1.1 The Course Context

"Design and Construction (AE1222-I)" is a project-based course, conducted throughout the second semester (third and fourth quarters) of the first-year aerospace engineering bachelor's curriculum at TU Delft. This course engages a cohort of approximately 400 students, who are organized into 40 teams. The primary objectives are for students to independently complete a full design cycle of an aerospace subsystem, collaborate on a complex team project with external guidance, and critically reflect on their work in a well-structured design report.

The first course project tasks students with designing the suspension system of a Mars rover—specifically, the Rocker-Bogie mechanism. This project is intended to reinforce concepts learned in the earlier courses of statics, dynamics, aerospace materials, and engineering drawing. In Fig. 1 and Fig. 2, it can be seen an example of the outputs of the students' work.

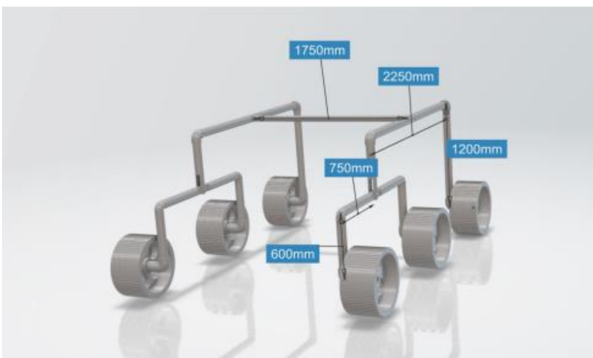

Fig. 1 Example of the render of the student's design

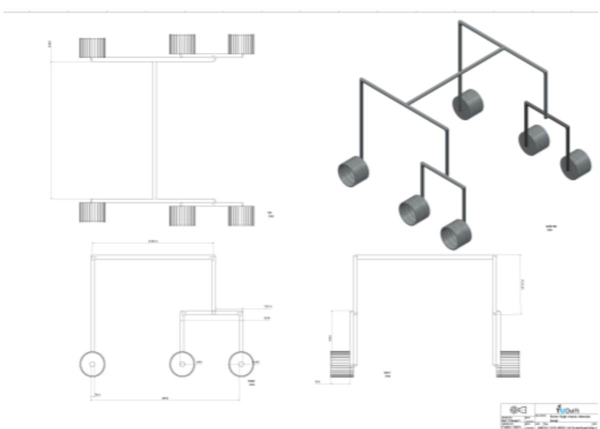
Fig. 2 Example of the student's drawings

To successfully complete the project, students are required to work through four distinct tasks.

The first task is to perform a literature study to become familiar with the topic and define design requirements based on best practices and issues met by past missions. In the second task, students are responsible for designing a Rocker-Bogie system that meets their specified requirements. The third task requires them to create a test proposal for their bogie design, outlining how they intend to validate its functionality. Finally, the fourth task involves compiling all their findings, designs, and proposals into a comprehensive design and test report.

Throughout these tasks, students are expected to independently seek out additional information as needed, relying on their own research and team collaboration before consulting the course instructors.

1.2 The Challenge

The central educational goal of this project-based course is to enhance students' appreciation of the practical applications of their acquired theoretical knowledge; however, this is not always achieved.

Throughout past editions of the course, it became apparent that students frequently treated the literature studies as a disconnected writing task rather than a crucial component of the engineering design process.

Moreover, many students approached the design of the Rocker-Bogie suspension system as a straightforward computational exercise, lacking a deep understanding of real-world structures and the specific design challenges posed by the Martian terrain.

1.3 The proposed solution

To address the identified challenges, it was decided to develop a hands-on introductory activity with the following goals:

- To deepen students' understanding of the concept of "design requirement".
- To guide students in formulating initial design requirements based on the Martian terrain, the rover's operational needs and on best practices and issues met by past missions, which will inform the design of their Rocker-Bogie suspension system.
- To provide students with initial and practical insights into the following topics, as starting points for their literature reviews: relevant characteristics of past Mars rovers' missions, perks of Rocker-Bogie suspension system, and Mars' terrain as both a science target and an engineering challenge.
- To enhance students' comprehension of the functioning of the Rocker-Bogie mechanism.

The activity was named **Mission M.A.R.I.J.N**, which stands for Mars Adventures: Research Initiative for Journey & Navigation. On top of the acronym reflecting the contents of the activity, the name Marijn is a Dutch name that is used for both men and women, which the authors found to be a nice inclusive detail [2].

2. Methodology

To provide a replicable model for developing similar instructional activities, the design principles and key considerations that informed the creation of this activity are presented.

The instructional design of this hands-on activity was inspired by the design principles from M. Gavioli et al [3], that aim to develop practical learning activities aiming at conceptual understanding in mechanics.

The design principles are:

1. Adopt guided inquiry-based instruction.
2. Allow direct experience of phenomena.
3. Incorporate diverse disciplinary representations.
4. Encourage the intertwining of experienced events and theoretical concepts through targeted learning tasks.
5. Monitor and guide students' progression from experience to theoretical models.

In addition to these design principles, the design process was guided by the learning objectives outlined in Section 1.3. These objectives provided the development team with a mutual clear understanding of the intended outcomes and ensured that all design efforts were aligned toward achieving the educational goals.

Furthermore, special emphasis was given to select existing demonstrative materials and resources from the faculty storage, and the activities were structured to optimize staff time and involvement, ensuring both efficiency and practicality in the implementation of the activity.

3. The intervention: Mission M.A.R.I.J.N

The introductory activity, "Mission MARIJN," tasks students with collecting critical requirements for the design of their Rocker-Bogie suspension system. The activity was structured as a series of three adventures, providing an engaging and progressive learning experience. To guide students and reduce the need for instructors' involvement, an activity booklet was developed to facilitate independent learning.

3.1 Activity Logistics

In the academic year 2023/2024, Mission M.A.R.I.J.N was strategically scheduled during the first week of the semester to ensure that students could fully engage with the content before starting their main project work. As the first pilot implementation, the activity was offered on a voluntary basis with five different 1-hour time slots, with each session accommodating up to 20 participants, allowing for a maximum of 100 students to enrol.

To maximize learning within the one-hour sessions, the timeline of Mission M.A.R.I.J.N was carefully structured as follows:

- **Introduction (5 minutes):** Every session began with a brief introduction, setting the stage for the activities and explaining their relevance to the Mars rover design project.
- **Meet Each Other (5 minutes):** Students were split into 3 groups, given time to introduce themselves and get acquainted with their group members, fostering a collaborative environment.
- **Adventures (45 minutes):** Each group was assigned to one of the three adventures stations. The adventures—*The Mars VR Fleet*, *Let's Rock, Let's Bo(o)gie*, and *Mars Geologists on Wheels*—were conducted in parallel, each of them lasting 15 minutes. After 15 minutes, the groups rotated to the next station, allowing every group to complete all three adventures by the end of the 45 minutes.
- **Wrap Up (5 minutes):** The session concluded with a brief wrap-up, where key takeaways were discussed, and students were encouraged to reflect on how the activity would inform their upcoming project work.

To manage each session, a team of 4 instructors were in the activity room, to answer questions regarding each of the adventures and to ensure a smooth flow of the groups.

3.2 Instructional materials

Students were guided through the activity by an engaging activity booklet, which was structured to align with the activity sequence outlined in Section 3.1.

The first pages of the booklet help students become acquainted with their group members (e.g., recording teammates' names and collectively choosing a crew name). The booklet also clearly explains the main task: their design team has sent them on a mission to collect critical requirements for the design of their Rocker-Bogie suspension system.

To successfully complete the mission, each student had to participate in all three adventures and gather the critical requirements, which were highlighted with a star in the booklet. This structure guides students' inquiry by specifying the data they need to collect while encouraging them to collaborate with their team on how to achieve this.

Students who successfully complete the mission were awarded a custom-designed sticker (see Fig. 3) resembling a mission patch, adding an element of excitement and immersion to the learning experience.

The core of Mission M.A.R.I.J.N consists of three hands-on adventures, each designed to immerse students in different aspects of Mars rover design. These adventures are discussed in detail in the following sections.

Fig. 3 Sticker design for Mission Marijn

3.3 Activity 1: The Mars VR Fleet

The first activity, The Mars VR Fleet, was built around the question: "**What are the characteristics of previous Mars rovers?**". It offers students an immersive virtual reality experience designed to familiarize them with past and current Mars rover missions. In this 15-minute session, students donned VR headsets (Fig. 4) and were transported to the surface of Mars, where they explored detailed simulations of all Mars rovers.

The Mars environment was created by the TU Delft media centre. The 3D models of the rovers introduced in the VR environment are available at the NASA 3D resources website [4]. The rovers included in the VR Fleet were Perseverance and Ingenuity, Curiosity, Scarecrow (earth test model of Curiosity), Spirit and Opportunity, and Sojourner.

This adventure allows students to experience the rovers at real scale and observe them up close, providing them with initial and practical insights into Mars rovers missions and their relevant characteristics, as starting points for their literature review.

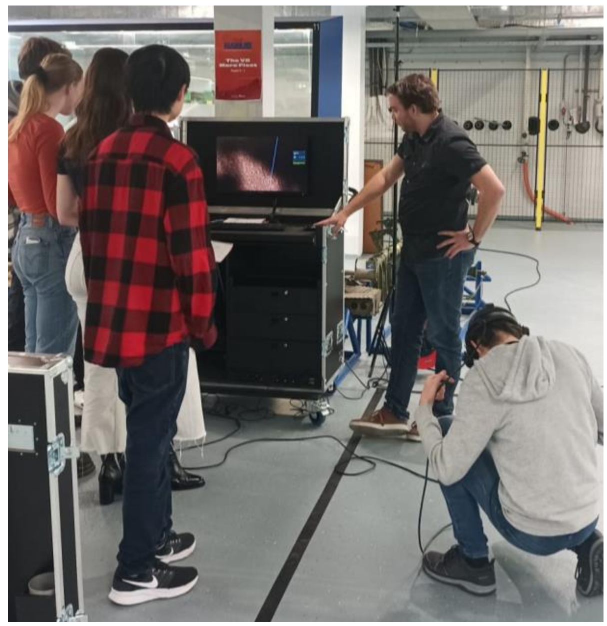

Fig. 4 Students during the VR activity

Moreover, the booklet asked the students to annotate some important information regarding the different rovers, to guide them in formulating initial design requirements for their own suspension system.

As seen in Fig. 5 they were asked to perform specific measurements with the VR-set measuring tool regarding the wheels and the rover height. This gave students not only a team purpose during the activity but also a feeling for the variability of the rover suspension system dimensions.

Rover name	Wheels diameter ✦	Body height from ground	Dimensions Rate from smallest =1 to largest = 6	Is this rover on Mars?	Remarks: Any special science payload, equipment, anything that catch your attention
Sojourner					
Spirit					
Opportunity					
Curiosity					
Scarecrow					
Perseverance (+Ingenuity)					

Fig. 5 Table extracted from activity booklet

Even if the current material available allows only for one a student at the time use of the headset, the rest of the crew could see the same in the adjacent screen. Within the time allocated for it, the team needed to divide the tasks and collaborate to get the maximum information possible.

3.4. Activity 2: Let’s Rock, Let’s Bo(o)gie

The second activity, *Let’s Rock, Let’s Bo(o)gie*, centres around the question "**How does the Rocker-Bogie mechanism work?**" This hands-on session allowed students to interact directly with a 1:4 scale model of the Perseverance rover, affectionately named MARCO (Mars Autonomous Rover Technology for Close Observation). The rover replica was built in house, with most of the components off-the shelf or 3D printed**.** The model was mostly inspired by the one developed in the website How to Mechatronics [5] with some modifications.

Fig. 6 Scaled Model MARCO

Since MARCO's mechanical behaviour closely mirrors that of its full-scale counterpart, interacting with this replica gave students the opportunity to explore the versatility of the Rocker-Bogie suspension system. Students were encouraged to test the system (see Fig. **7**) by driving the model over Martian-analogue rocks of varying sizes and degrees of roughness. This practical exercise not only deepened their understanding of the Rocker-Bogie mechanism, but also emphasized the need to balance mobility with stability in rover design.

Fig. 7 Student driving scale Model MARCO

The booklet instructed students to record MARCO’s wheel diameter, measure the size of the largest obstacle it could overcome, and find a method to calculate its average speed. Additionally, students were asked to sketch the Rocker-Bogie mechanism when one of the wheels was positioned on a rock. At the end of the session, students were encouraged to take a group picture using MARCO’s camera.

Fig. 8 Group of students taking part of the activity

3.5 Activity 3: Mars Geologists on Wheels

The third and final activity, Mars Geologists on Wheels, was centred around the question, "**How does the Martian terrain influence rover design?**" This activity focuses on the intersection of geology and engineering in the context of Mars exploration. During this 15-minute session, students learned that the Martian terrain serves as both a scientific target and an engineering challenge in the design of Mars rovers.

This acts as a bridge activity between the VR set and the “Mars Yard”, making use of the cabinet where the materials are stored seen in Fig. 9. The cabinet, named: Mobility on Mars, is part of the Aerospace Engineering Study Collection and can be visited by the students at any point of the year. It usually houses MARCO (except when the activity is running) and it contains geological samples, and 1:1 models of the wheels of the rovers Curiosity and Spirit/Opportunity.

Fig. 9 Students working with the Exhibit

The booklet guides students through the examination of various geological samples (See Figure 10). that a rover might collect as biomarkers on Mars or encounter during its traverse

Figure 10 Geological Samples in the Exhibit

Students were then asked to analyse the Spirit and Curiosity missions (see Fig. 11) by recording their landing sites, science targets, wheel diameters, grouser designs, and any navigation issues they encountered on Mars. Students then discuss how this data would influence their own rover design decisions. This activity highlights the interdisciplinary nature of Mars exploration, demonstrating how geoscientific insights directly shape the engineering solutions developed for planetary exploration missions.

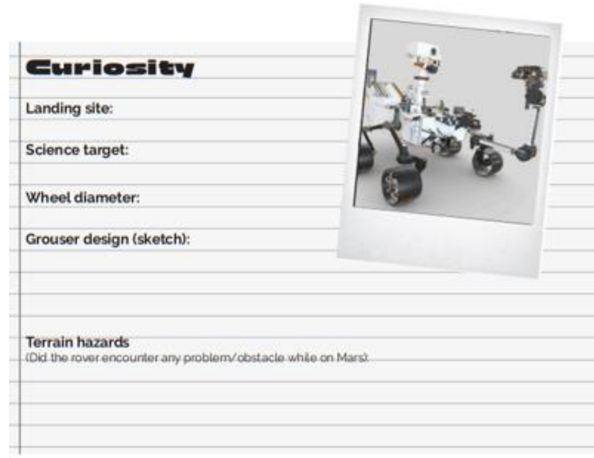

Fig. 11 Extract of the activity booklet

3.5 Discussion on the instructional design of the activity

In the instructional design of *Mission M.A.R.I.J.N.*, the design principles introduced in Section 2.1 were carefully integrated to guide and monitor students' progression from direct experience to theoretical understanding (5).

Guided inquiry-based instruction (1) was consistently applied by encouraging students to find their own methods for collecting the critical design requirements for the Rocker-Bogie system, which were highlighted in the activity booklet.

Students were also given opportunities to directly experience phenomena (2), as they could appreciate the real dimensions of Mars rovers within *The Mars VR Fleet*, by driving the 1:4 scale model of the Perseverance rover (MARCO) over obstacles in *Let’s Rock, Let’s Bo(o)gie*, and by directly observing Martian-analogue rocks and the 1:1 replicas of rover wheels in the cabinet for the *Mars Geologists on Wheels*.

This hands-on experience was further reinforced by incorporating diverse disciplinary representations (3), including physical and VR models, tables, diagrams, sketches, terrain maps and more. Finally, targeted learning tasks (4) helped students link their direct experiences with theoretical concepts through various degrees of reflective tasks, from calculating MARCO’s speed and sketching the Rocker-Bogie mechanism, to discussing how their observations and collected data would inform their rover designs.

4. Results

The effectiveness of the activity was assessed via a student survey. This survey was sent to the participants after the full project of the Rocker- Boggie design was completed, and their report submitted. Out of 70 participants of Mission Marijn 23 responded to the survey and their responses are briefly discussed below.

The students gave the activity a 26 NPS (Net Promoter Score). NPS is a metric initially designed for measuring consumer satisfaction but that has also been recently been applied to analyse the success of undergraduate programs [6]. This value (above 0) indicates that is likely that participants will recommend the activity to the students of the following years, and that they were happy with their participation.

The students were also asked regarding their perceived learning in each of the adventures. Each adventure was asked specifically as it follows:

- How much did the adventure "**the VR Mars Fleet**" help you discover characteristics of previous Mars rovers?
- How much did the adventure "**Let's rock, let's bo(o)gie**" help you understand how the rocker bogie mechanism works?
- How much did the adventure **"Mars Geologists on Wheels**" help you consider the impact of Martian terrain on rover design?

It can be seen in Fig. 12 that the adventures: "the Mars VR fleet" and "**Let's rock, let's bo(o)gie"** were seen to have a higher perceived learning than the "**Mars Geologists on Wheels"**. This can be related to the fact that the means of learning: observing the cabinet and taking notes were less appealing and thus students lost interest during the activity.

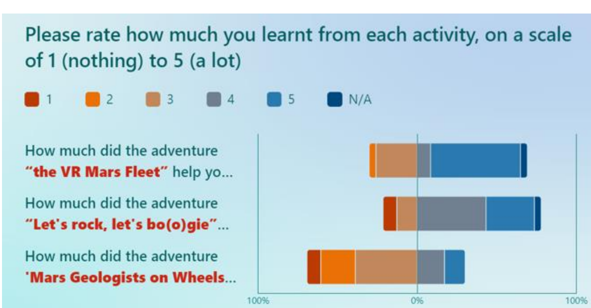

Fig. 12 Perceived Learning Results

Another interesting output of the survey related to the question: "Please rate how helpful each activity was with the Rocker Bogie assignment on a scale of 1 (not helpful) to 5 (very helpful)." As can be seen in Fig. **13**, they were broadly positive about the usefulness of the activities in their assignment. Again, the activity "Mars Geologists on Wheels" was seen as the least useful, aligned with the perceived understanding.

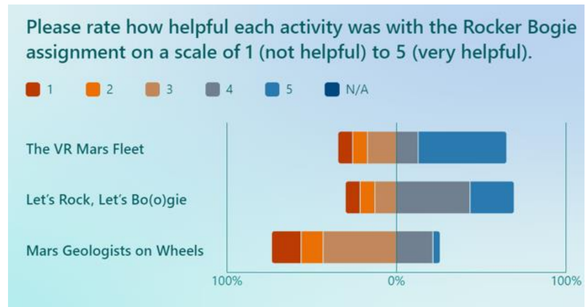

Fig. 13 Perceived usefulness of each activity

The initial results indicate that students who participated in Mission M.A.R.I.J.N demonstrated a better understanding of the design requirements and were more engaged in the project. For future iterations, some redesign of the Activity Mars Geologist on Wheels should be considered.

6. Conclusions

Mission MARIJN demonstrates the potential of immersive, hands-on learning activities in enhancing the educational experience of aerospace engineering students. By introducing a Mars exploration context, the activity successfully engages students in the application of theoretical knowledge to practical design challenges.

Feedback from participants suggests that the activity positively impacted their understanding of design requirements and mechanical principles, especially through the VR and scale model components. However, the lower perceived usefulness of the Mars Geologists on Wheels segment indicates room for improvement in aligning this portion with the project's core objectives.

Overall, Mission MARIJN offers a promising framework for future course enhancements aimed at improving student learning outcomes and fostering a deeper connection between theoretical knowledge and engineering practice.

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