# Space-Grounded

## Developing an Antidepressant Inhalation Device Using Natural Materials to Enhance Crew Well-being


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The journey to Mars is the next possible space venture for human space explorers after the Earth-Moon system. The psychological health of the crew may be impacted by spending roughly 1000 days in a confined habitat. To address this, tools and devices must be developed to improve the crew's health by addressing their higher-level needs beyond basic physiological and psychological needs. In this context, we present a portable and natural antidepressant inhaler device that takes into consideration human factors. The device creates a chemical called geosmin from dry soil to generate petrichor. Inhaling petrichor may help treat depression by increasing specific brain chemicals, such as serotonin and norepinephrine. We describe the steps we took in implementing natural material - soil - in our design process, including the ideation, developing the device, and a preliminary usability testing, to explore the potential of utilizing natural materials for space well-being.



CCS CONCEPTS • Human-centered computing~Interaction devices • Insert your second CCS term here • Insert your third CCS term here

**Additional Keywords and Phrases:** Petrichor, Antidepressant, Deep Space, Human-Factors

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## 1 INTRODUCTION

One possible destination for astronauts in the near future is Mars. With the help of such an interplanetary space mission, humanity can spread further into the solar system. However, humanity does not have much experience in long duration deep space missions. In this context, astronauts may face challenges related to their safety, mission success, and physiological and psychological well-being throughout their travel [3]. This research aims to assist the crew's

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psychological health, specifically their depressive mental status, in the context of first-ever long-duration deep space mission. It introduces a drug-free assistive device that uses petrichor to help combat depression and discusses opportunities of using natural material – soil in this case - for space exploration. As the crew must remain in an isolated environment while traveling to and from Mars, astronauts may need to deal with depression [31][40]. What was it like when Christopher Columbus decided to sail west across the Atlantic Ocean with a crew of 90 men for the first time [13]? The particular feelings they experienced are unclear, although it may be assumed that exploring the "unknown" is never easy. To increase the chances of success in exploring unknown space, we must ensure the safety of our crew during long periods of space flight. This study examines pertinent works that reduce crew anxiety and depression during space missions. Our project Space-Grounded—a novel inhaler device—and the development process are presented after establishing the research environment, context, and opportunity. The presentation was followed by preliminary usability studies, including the involvement of a person diagnosed with depression. The limitations of our research are then covered, followed by a discussion and conclusion.

This research was conducted not to present clinical evidence of the device but to explore new possibilities and gain insights into the implementation of natural materials in relation to space exploration and crews' well-being [68]. The central question we addressed was: How can natural materials be implemented to reinforce crew well-being for the future of space exploration? Our contribution lies in the design and development of a unique portable device that may reduce depressive symptoms by utilizing a natural material – soil.

## 2 RELATED WORK

Deep space exploration poses risks to human health and well-being, including isolation, invasion of privacy, radiation, changing gravity, hostile/closed conditions inside a space vehicle, and even brain degradation [32][59]. The following section discusses relevant research initiatives and approaches aimed at reducing depressive symtomps and anxiety in the context of space exploration.

### 2.1 People-Plant Interactions in Long-duration Missions

Studies on the therapeutic advantages of gardening in anxiety reduction and improvements in mental health status have been conducted for decades [1][8][26]. Long-duration space missions and the crew's well-being have been linked to the advantages of gardening's connection to nature. Early studies highlighted a substantial body of empirical data to support the idea that active plant interactions can support astronauts' cognitive and behavioral health during lengthy space journeys [43]. Furthermore, long-term space trips to Mars were predicted to eventually need to engage in farming to provide food as early as the late 1980s [64].

### 2.2 Immersive Technology for Mental Health in Space

Simulations in virtual reality (VR) have helped enhance psychological well-being. According to prior studies, the VR application efficiently distracted cancer patients and burnt sufferers from agony [14]. Additionally, eating disorder sufferers have benefited from its use [14][60]. The immersive environment has also improved body image and reduced sadness in obese patients [60]. Deep space missions have also been an example of such a research opportunity. Previous studies hypothesized that using immersive media, such as virtual reality (VR) and augmented reality (AR), could support astronauts in maintaining a good mental state through therapy, particularly for those who are cut off from the comforts of terrestrial life and activities [55][5]. The difficulties associated with privacy, social isolation, and sensory deprivation in a spacecraft's cramped conditions can be significantly reduced by immersive experiences.

### 2.3 Managing Space Food Waste with Fermentation

Early findings point to fermentation as a potential method for handling food waste during long space missions [12][11]. Additionally, composting food waste in space could offer astronauts options for recreation and natural contact within confined spaces, promoting their welfare. Food waste can be used in a fermentation process to grow food, reusing food waste to create new values. Additionally, the procedure delivers a range of sensory qualities, including tastes, textures, and nutritional information, which can enhance mental health through sensory stimulation [11][18].

### 2.4 Decoupled Communication in Space Missions

Decoupled communication is one initiative that could improve the crew's well-being. Project Martian Delight [31] uses a reward system in the context of deep space missions to strengthen the crew members' sense of connection to their families [38]. Every time an astronaut finishes a task during a protracted space mission, the device releases a heartfelt gift from their loved ones back on Earth. These prizes are typically tangible objects that are special or unforgettable and connect the feelings of the crew and the families. Each layer of the egg construction, which resembles a Matryoshka doll, includes a different kind of reward. The decoupled communication system cannot offer crew members and their families instantaneous communication like that experienced on the internet. However, it can provide an immediate attachment through a sense of connection via a meaningful item or channel they share, which benefits the crew members' mental well-being.

### 2.5 Sensory Stimulation and Interaction

Previous studies looked at how human-material interactions could stimulate the sense of touch and investigated how surfaces, color, light, sound, taste, and scent could reinforce astronauts' well-being on long-duration space journeys [2][45][66][3][58][11][16][47]. For instance, one project explored how to design a pillow that would be comfortable for the crew in a zero-gravity environment [3]. Another project investigated an experimental portal or booth that creates an immersive physical telepresence experience by simulating various locations' sights, sounds, and smells [58]. Also, a project explored how to manage food through fermentation processes [11].

### 2.6 Companion Robots

The rising interest is observed regarding the use of companion robots, otherwise known as socially assistive robots (SARs), in mental healthcare [50][56]. Studies have shown that SARs decrease the loneliness of isolated individuals such as the elderly [52][4][25], encourage positive moods and improve well-being [7][34][61], reduce anxiety or depression [28][29][62][63], and enhance social human-human interactions [50][54]. Due to these positive effects of SARs regarding mental health assistance, many agree to consider social robots as potential companions [15]. Such approaches are also being considered as a way to support the well-being of crew members during confined deep-space travel [10][22][49].

## 3 OPPORTUNITY: PETRICHOR

Previous research and projects have aimed to address depression and well-being in the context of space exploration, but none have specifically looked at using petrichor – a smell from soil - to alleviate depression for the crew's well-being. The following section explores petrichor and rationale behind its usage.

### 3.1 What are Petrichor and Geosmin?

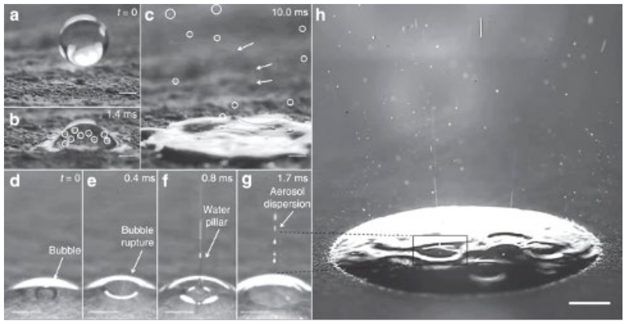


Figure 1: Aerosol generation from droplets hitting dry soils and porous surfaces [24].

Have you ever experienced an earthy smell in the air after rain? The earthy odor or aerosol created when rain falls on dry soil is known as petrichor. Some plants, damp clay, sediment, and rock contribute to the petrichor odor. Geosmin, a chemical generated by soil-dwelling bacteria known as Actinomycetes, is the source of the petrichor aroma, according to mineralogists [24][6][48]. Figure 1 depicts what scientists discovered using high-speed cameras when a raindrop hits dry soil—these aerosols could disperse petrichor's earthy fragrance [24]. When a raindrop contacts dry earth, it immediately captures little air bubbles at the site of contact. Then, like in a glass of champagne, these little air bubbles rise upward, eventually exploding aerosols.

### 3.2 Soil, Petrichor and Depression

Initial studies conducted using lab mice found that exposure to "friendly" bacteria, commonly found in soil, led to the activation of brain cells that produce serotonin, resulting in behavioral changes similar to those seen with antidepressant use [35][41][44][20]. It has also been suggested that spending time in forests, a practice known as "forest bathing," can reduce feelings of anxiety, stress, and depression, due to the presence of the earthy scent of soil [33][20]. Researchers have also been interested in the potential connection between soil and quality of life, particularly in cancer patients who showed improvements in quality of life after receiving treatment with the soil-derived bacteria Mycobacterium vaccae [35][42][65]. In a recent study involving twenty-nine adult participants, soil-mixing activities were performed using sterilized soil. The findings indicated that soil contact can affect human metabolic and autonomic reactions, contributing to reduced depressive status - blood samples were collected twice after each soil-mixing activity to measure variations in the brain-derived neurotrophic factor [67].

### 3.3 Why Soil and Petrichor in Space?

As astronauts venture to explore deep space such as Mars in a confined environment, they will be cut off from the comforts of terrestrial life and activities for a long term. This highlights the importance of incorporating elements of Earth's materiality, such as soil, into the design of space habitats. Currently, no studies are exploring the practical applications of petrichor within the context of space explorations. However, by considering its unique properties, we believe that it has the potential to reinforce comfort and well-being for astronauts living in space. Our project also poses new challenges in implementing natural material - soil - in the context of space interaction for well-being.

## 4 DEVELOPING THE DEVICE: SPACE-GROUNDED

In the following sections, we explain the process of developing the experimental prototype device. This includes considerations for preserving the smell of petrichor from dry soil within the device, addressing structural factors, determining the hardware shape, designing a soil bag, and addressing concerns related to human interactions.

### 4.1 Early Ideas and Inspirations

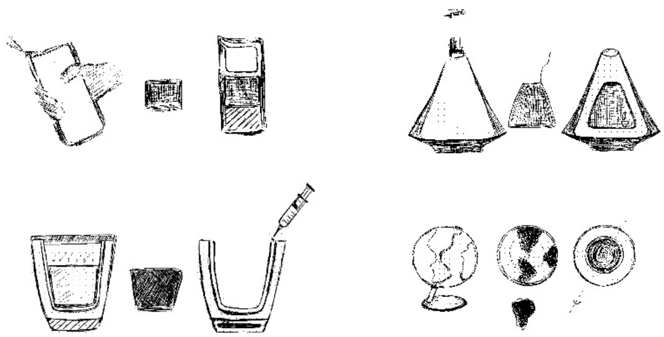

Figure 2: Early investigations and ideas.

Before developing the device, we needed to investigate and create various concepts, forms, and architectures capable of holding and releasing petrichor. This divergent thinking stage was essential prior to settling on a specific device design, as it stimulated the generation of diverse ideas and solutions [17]. The initial brainstorming and sketching process, which lasted a week due to time differences between countries, was carried out by the authors, who comprise a space architect and aerospace engineer with experience in jet propulsion, a mechatronics specialist who is an expert in robotics, an industrial designer, a design engineer, and a textile design expert.

We depict a humidifier-style petrichor distributing apparatus (Figure 2 top right) so that all crew members can simultaneously benefit from the earthy scent for their mental well-being. While the concept is advantageous to all parties involved, it also invades privacy by producing excessive stench in a space habitat's enclosed environment. The following (top left) was a pressing type that allowed one to spray the scent directly on their face. The Earth-shaped structure in the bottom right resembles Earth's land and oceans by having water and soil on its surface while being in zero gravity. The "cup of the soil" (bottom left) allows one to add water to a "soil bag" (instead of a tea bag) and then breathe in the aroma. As "tea-mindfulness" is a great way to stop for a moment during the day, we concluded that the concept of a "cup of soil," developed from the idea of a cup of tea, is intriguing. Making and drinking tea may be meditative [27][57][36], and we wanted to incorporate this aspect of interaction into our device for astronauts' well-being in addition to petrichor inhalation for depression. We also looked into devices or goods that provide a ritual-like experience, like cigarettes, including e-cigarettes, perfume, and coffee, in order to understand what other behavioral or interactive factors support well-being [39].

### 4.2 Device Interaction & System Configuration

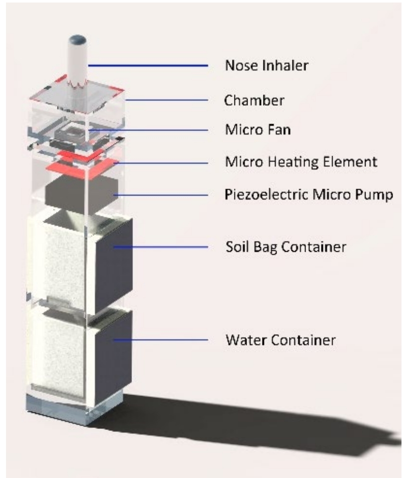


Figure 3: CAD Structure of the device

The petrichor inhaler device (Figure 3) consists of a breathing apparatus, a chamber, a microfan (15 mm x 15 mm), a heating element (15 mm x 15 mm), a step-up converter, a piezoelectric micropump (25 mm x 25 mm x 7 mm), and containers for soil and water with some general electronic components, including an IC chip. A 3.7v polymer lithium battery powers the device, and a custom printed circuit board (PCB) is located on the side (PCB size: 29 mm x 44 mm). To use the device, water and a dry soil bag are placed in the designated containers. Once connected, the device can be turned on. Before the smell of petrichor is released from the chamber and dispersed by a micro fan, the apparatus goes through three phases.

#### *4.2.1 Phase 1: Dripping Water on the Dry Soil Bag*

Phase 1 begins with the device supplying water droplets by pumping the water from the device's bottom to the container holding the soil bag (Figure 3). This process is to facilitate the release of petrichor from dry soil. It does so by simulating raindrops falling on dry soil from the top, similar to the process that occurs in nature (Figure 1). With a PVC hose and a specialized tiny piezoelectric pump, we were able to supply 7ml of droplets every minute, which is a specific volumetric amount. Phase 1 pumps water gently for 100 seconds. The device activates a red LED on the PCB side to indicate that it works while pumping droplets (Figure 5). Additionally, we purposefully set the timer for 100 seconds to allow astronauts to reflect and unwind as the device prepares for the service—much like making a cup of tea or coffee—like a ritual.

#### *4.2.2 Phase 2: Increasing Temperature*

The device enters Phase 2 after the droplets are added to the soil bag container. During this phase, the device is kept in standby mode for 20 seconds to allow for full moistening of the dry soil. The temperature within the device then rises for 60 seconds as heat is produced (Figure 3). This temperature increase helps odor molecules disperse more quickly into the air, enhancing the smell [37]. The moistened dry soil also supports this process by adding moisture in addition to heat [9]. During Phase 2, the device illuminates an orange LED to signal its current operation. The durations of waiting in Phases 1 and 2 were determined after conducting over 12 tests using the soil bag we designed. These tests involved calculating the duration of soaking the soil bag, heating up the device, and determining an appropriate time for the ritual-like wait during Phase 1 and 3.

*4.2.3 Phase 3: Preparing Inhalation*

In Phase 3, the green LED activates to indicate that the device is ready for use. The chamber has an earthy odor. Now the user brings their nose near the pipe and positions it correctly. Once the nose is positioned, the user can turn on the micro fan to gently drive the warm, earthy aroma through the pipe. After three minutes, the device shuts off by itself (including turning off the green LED), and the ritual is over. It works somewhat like an e-cigarette [30]. By removing the soil bag and turning on the main power and the fan, the device starts to self-clean any remaining moisture from its pump, chamber, and PVC hoses.

### 4.3 Hardware Structure Design

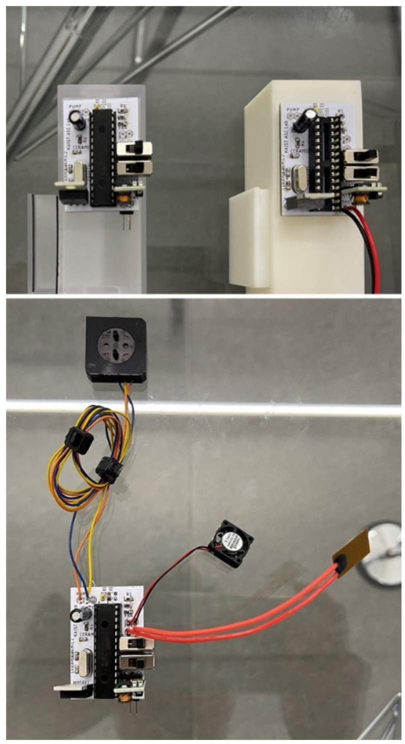

Figure 4: Various prototypes testing

To design the appropriate hardware structure for our device, we employed stereolithography (SLA) printing. We prototyped a total of five hardware architectures through three iteration phases, which took around two months. This time includes the SLA printing, PCB fabrication, reprinting, designing soil bags, and crafting processes (Figure 4, 6, 7). This procedure was necessary to determine the ideal device size for water and soil bag containment, as well as to design an appropriate initial system. For instance, our first prototype included some holes on the side of the device to allow the power circuit to pass through. However, in our second version, we removed these holes because they might allow petrichor inside the device to escape. Additionally, our initial structure design was printed in white, but we changed it to a half-transparent material so that we could see through its structural layers and activation processes. After three rounds of iterative prototyping and consideration, we settled on a rectangular-shaped design for our device, measuring 142 mm x 34 mm x 34 mm (Figure 5). The following factors were considered when designing the hardware structure of the device.

1. Shape & Size—compact and portable design for ease of use and carrying
2. Material—durable material to withstand regular use and accidental bumps in space
3. Color—neutral color that does not distract visually
4. Indicator—clear LED display of each phase of the device
5. Power—appropriate capacity to run the system
6. User Interface—simple and intuitive user interface
7. Safety & Maintenance—easy to clean and maintain the device to ensure hygiene and longevity.

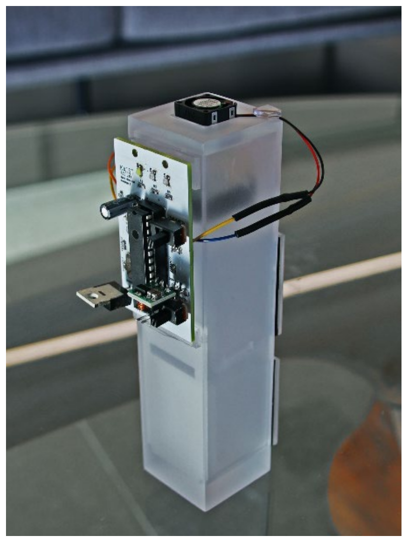

Figure 5: Device without a soil bag and water

Since the purpose of this research was to envision and explore novel possibilities and gain insights into the implementation of natural materials for the future of space exploration, we did not conduct any clinical studies to determine whether the material – in this case, SLA transparent resin – used for the device structure is appropriate for inhalation, given the certain amount of heat produced during Phase 2 of the device. Our primary focus in this research was on the challenging, novel implementation of soil and the design of a potential device for enhancing space well-being. We considered that the material could be changed to other clinically appropriate materials (e.g., medical-grade plastics) in later stages of research.

### 4.4 Soil Bag

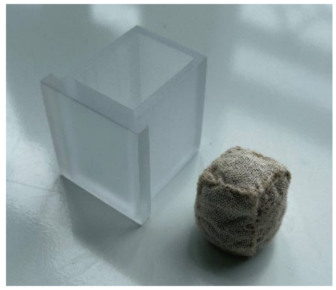

Figure 6: Soil bag and the container

We developed a unique dry soil bag resembling a tea bag that fits inside the device (Figure 6). This was important because introducing dry soil into a microgravity environment could contaminate the tightly controlled enclosed space, causing soil particles to float everywhere. Additionally, in a microgravity environment, water droplets do not fall, so we had to create a fabric capable of absorbing water directly from the pump. We used sterilized soil [67] for our soil bag and collaborated with a textile designer and expert to create a small, square dirt bag to be housed inside the apparatus. The designer utilized a sanitary, water-absorbing fabric made of pure cotton called Sochang, also known as Ganghwa silk, a traditional cloth from Korea. She chose this material because she was more experienced in handling and fabricating such sanitary cotton materials. When raindrops hit the dry soil from the top during Phase 1 of the process, we used this highly absorbent cloth to ensure that the soil may be adequately soaked from all sides. The textile expert stitched a thin square structure fabric with the material before filling the dry soil and finishing the sewing. Once it has dried, the soil bag can be used again [23]. It measures 18mm in length, 18mm in breadth, and 25mm in height (depth). Before assembling our soil bag from water-absorbing fabric, we also tried to create a fabric that could feed the soil nutrients. Finding a technique to hold the soil like a regular fabric while maintaining the soil's health and nutritional content was one of the difficulties in developing this fabric. Three different fabrics were tested for this purpose.

Figure 7: Various produced fabrics: Left: powdered eggshell mixed with paper fabric, Middle: coconut shell mixed with eggshell and paper fabric, Right: ripened banana peel mixed with paper fabric

- The first one (Figure 7 left) was blended with a ratio of 50% powdered eggshell and 50% paper fabric. Eggshell is a well-known substance that provides nutrients to soil [21], and we hypothesized that using this substance to create a fabric that could serve as a soil container might improve soil quality when wet. The two combined materials were then run through a dehydrator for 90 minutes at 60 degrees Celsius.

- The second type (Figure 7 right) of fabric was created by blending ripe banana peel (65%) and paper fabric (35%). Soil is reported to benefit significantly from banana peel [46]. Additionally, it has a high fiber content that can help in creating a sturdy cloth that can hold dry soil. The dehydration process for the combined materials was the same as for the first material.
- The third fabric (Figure 7 middle) was made from a blend of paper cloth (45%), coconut shell (40%), and powdered eggshell (15%). We thought that combining the high nutritional value of banana peel with the high fiber content of coconut peel would create a fabric capable of retaining dry soil even when it became soggy.

Despite conducting multiple experiments, we ultimately selected a pure cotton water-absorbent fabric as the most suitable option. This decision was based on the fact that the three other fabrics tested lacked the durability to maintain dry soil when wet. Regardless of this outcome, our efforts were meaningful as they aimed to improve soil quality. We decided to conduct further testing to create a more suitable fabric for our future studies.

## 5 PRELIMINARY USABILITY / INTERACTION TESTING

| Participants | Age | Gender | Diagnosed with depression |
|---|---|---|---|
| P1 | 36 | F | Yes |
| P2 | Not available | F | No |
| P3 | 38 | M | No |
| P4 | Not available | F | No |

Table 1. Demographics of preliminary usability study participants

We conducted preliminary user testing to understand the interactivity of the device – not its medical improvement. Interactivity here mainly refers to ergonomic factors, such as the device's shape, size, grip, interface, and accessibility. Since we were unable to mimic a microgravity environment, we primarily focused on testing the device's structural factors in relation to user interactions. For this preliminary user testing, we recruited four participants (Table 1), including a female volunteer with a diagnosis of depression (P1), one male (P3), and two female participants (P2, P4) who agreed to provide feedback on the device. Previous research has shown the potential for soil and petrichor to improve depressive status [35][41][44][20][33][42][65][67]; therefore, our preliminary user testing specifically aimed to assess the interactivity of the device within this context.

P1 was instructed to take the device home and charge it as per the instructions provided. She was also asked to use the device three times a day and focus her feedback on usability and interaction quality rather than improvements related to her depression. In contrast, we organized a 90-minute workshop session for P2, P3, and P4. The workshop session started with an introduction to deep space missions and petrichor, with a focus on improving the device's interaction. This separate workshop arrangement between P1 and the other participants was made because P1 was not comfortable actively joining a workshop-type activity with other people – which might be attributed to her depressive symptoms.

### 5.1 Feedback

P1 reported a strong enjoyment of inhaling the scent of petrichor released by the device. She was intrigued by the concept of using an earthy scent to treat melancholy but expressed some hesitation due to the device’s rarity and uncertainty about its efficacy in treating depression. P1 believed that the device’s interactivity could be improved, as she found the current version to be overly mechanical due to visible electronic components. She suggested that the power and fan controls—currently controlled by two slide switches—could be relocated or altered to improve interactivity. For example, she suggested that the fan switch could be changed from a slide switch to a push-button switch for easier differentiation between the two controls. P1 also described the pump's sound as amusing and calming and reported feeling meditative while waiting for the device to prepare for inhalation.

P2 and P4 also expressed enjoyment of the waiting period, describing it as offering a sense of expectation. While all female participants mentioned difficulty gripping the device due to its size (142mm x 34mm x 34mm) and square shape, P3 (male) did not see issues regarding the device's size. P1 and P4 recommended a cylindrical shape as an alternative, and P1 suggested relocating the side-mounted LED phase indicators to the top for easier monitoring. P2 reported that the brushless fan was too loud and disrupted the inhalation process and expressed a desire for a gentler wind flow. P3 provided feedback related to new systems, commenting that it would be desirable to design a system that operates without electrical components, similar to a cup of tea. He also suggested that the device's containers could fit better to reduce wobbliness. P4 asked about the possibility of using the device on Earth. Unlike P1, who mainly provided feedback related to the interactivity of the device, P2, P3, and P4 expressed interest in sharing additional ideas beyond usability in the free-flowing atmosphere of the workshop environment.

### 5.2 Finding

To analyze the contents from the workshop and P1's feedback, we primarily relied on our observational notes, which captured most of the qualitative data from the workshop discussions and an interview with P1. We believed this approach would effectively preserve the conversational data, allowing us to revisit it collectively at any time and anywhere digitally.

Feedback from the preliminary study indicates that there are aspects we need to refine and investigate further to enhance interactivity. One particularly valuable finding was the importance of accommodating different hand sizes. Given that astronauts embarking on Mars missions will comprise a mixed-gender group, it is crucial to incorporate this feedback into our hardware design—the initial device size was based on a male's hand grip. We also identified potential improvements in the robustness of the two containers, the placement of phase indicators, and the noise level of the fan, which could be addressed in future studies. A key insight and finding from this preliminary user study is that designing a tool or device for space exploration presents a formidable challenge for researchers who lack access to adequate environmental resources, such as the ability to simulate microgravity, as in this particular case. This insight was derived from the fact that participants kept asking about the case and possibilities in a microgravity environment – where researchers, including an aerospace expert, did not have experience in actual microgravity environments and, therefore, were not able to answer participants' concerns with clarity. This led us to question whether there is an affordable way to create a testbed or platform that supports the development of space-relevant devices and products for effective research investigations, and what types of alternative testing methods we could envision when it comes to human-computer interaction for space exploration.

## 6 LIMITATIONS & DISCUSSIONS

Our future research direction is described here, along with its constraints.

### 6.1 Zero Gravity Environment

The tool is intended for astronauts on lengthy space missions. This indicates that the device needs to be tested in a zero-gravity setting. Due to a lack of resources, we have not been able to test in this environment to this point. Although the device needs a microgravity environment for advanced usability testing, this condition is not necessary to test for effects on the user, such as benefits for reducing depression. The following stage of our investigation might allow us to investigate this issue separately.

### 6.2 Interdisciplinarity: Limited Expertise

The study assessed the initial interactivity of the device through preliminary user studies. In future rounds of research, we intend to explore improvements in depressive status through our device by working with medical professionals, even though previous research has shown the potential for soil and petrichor to improve depression [35][41][44][20][33][42][65][67]. We also think it would be beneficial to involve other experts beyond the medical sector, as the development of the device has complexity that requires knowledge from various disciplines, including psychology, chemistry, and medicine. Our current expertise is in design, engineering, and aerospace.

### 6.3 User Study

This research included only a limited number of user studies to understand the initial interactivity of the device. We believe the user study aspects should be improved. However, at the same time, we also question whether it is necessary to conduct further user testing without the presence of a microgravity environment. This was also one of the reasons that we conducted a preliminary user study instead of a broader study on the device's interactivity with users. We considered conducting user studies during parabolic flights, but due to the limited research budget, we did not proceed further. We believe this accessibility issue can be considered in relation to one of our findings, which involves the potential for developing an affordable testbed or platform.

### 6.4 Compressed Soil

We were unsure how much petrichor was needed to lower particular depression levels, although both the meditation technique or ritual and petrichor could enhance a certain depressive condition. There were not any studies or interventions connected to this. This made us wonder if compressed soil could produce more petrichor, which might have a better effect on depressive status. In our future research, this component can be further examined in addition to the fabric design in collaboration with other experts.

### 6.5 Drugless Antidepressant?

In this research, we propose an experimental device that offers a natural antidepressant. However, considering there are already several medications and pills available to treat depression, is such a device truly necessary? Our goal is not to create something that replaces existing depression treatments. Instead, we aim to investigate a novel possibility that could complement current approaches to treating depression for the future of space exploration. Combining synthetic drugs and natural antidepressants might lead to more effective recovery for those affected. We believe that such support will be beneficial for the first-ever long-duration deep space mission.

### 6.6 Hardware of the Device

We have discovered technical issues with the device’s robustness. The micro piezoelectric pump in particular, appears to be overly delicate and brittle with a built-in driver, which means that a slight physical bump or electrical noises can harm its internal system. Since the micro pump itself is also a prototype, we will have to consider a way to increase its durability and functionality. Besides, the two containers need to fit better with a better magnetic connection. Other issues are related to size of the device. We shall ensure that the device can be easily grip by any genders.

### 6.7 Design of Soil Bag

In this study, we tried to design a cloth cover that could feed the soil with nutrients. We believed that nutrient-rich soil would produce petrichor more effectively. But despite our three attempts to make this fabric using eggshell, coconut shell, and banana peel, they fell short due to a problem with the fabric's durability. To address this problem, we are thinking about adding more paper cloth to the material mix. Additionally, we are looking into additional materials that can increase the dirt bag's general durability. Seaweed, a great provider of fiber, is one potential substance. While the design of the soil bag is not the main focus, we still think that the consideration around this issue is valuable as it is related to the quality of soil, which is relevant to petrichor.

## 7 CONCLUSION

In this paper, we explored and introduced new possibilities for the implementation of natural materials in relation to space exploration and crew well-being. We proposed an experimental device that aims to support the mental health of space crew members through petrichor—a drug-free method. The device is a portable inhaler designed for individual use by crew members, intended to help those struggling with depression during deep space missions. One key insight and finding from this study is that developing a device or tool for space exploration is a formidable challenge for researchers who lack access to adequate environmental resources or simulations. This led us to consider alternative methods for device testing as well as the development of an affordable testbed or platform to democratize access to space research for human-computer interaction. Although our research still has room for improvement, we hope our contribution in developing the experimental device and our findings could stimulate discussion around the future of space habitat design for deep space exploration.

## 8 ACKNOWLEDGMENT

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