

Understanding Space Pharmacy Education for Pharmacists with the Teeter-Totter Model: If-Then Logic Model and Socio-Ecological Framework for Space Pharmacy Council

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Abstract

Letter to the Editor

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Dear Editor,

Pharmacists play a critical role in minimizing medication-related risks and ensuring patient safety worldwide[1]. Their expertise in medication management, pharmacokinetics, and patient counseling significantly reduces adverse drug reactions, enhances treatment outcomes, and safeguards public health[1]. Pharmacists exist globally because they protect patients from the potential dangers of medications, ensuring appropriate drug use and preventing medication errors. Given their indispensable role in optimizing pharmacotherapy on Earth, it is essential to extend their contributions to space medicine. The unique challenges posed by space travel—such as microgravity-induced physiological changes[2], radiation exposure[3], and resource limitations[4]—necessitate a specialized approach to medication safety and effectiveness beyond our planet.

To address these challenges, the PAR (Participation, Action, Research) model was previously introduced in the context of advancing Astropharmacy, along with the proposal for establishing a Space Pharmacy Council to guide research, standardization, and training within this emerging field[5]. This letter further expands on these concepts by emphasizing the critical role of Space Pharmacy Education for pharmacists, utilizing the **Teeter-Totter Model** to illustrate the balance between conventional pharmaceutical education and the specialized knowledge required for space medicine. As space exploration advances, the need for specialized pharmacy education in space medicine becomes evident. Furthermore, I would like to discuss an “**If-Then Logic Model**” to outline the systematic approach for implementing a Space Pharmacy Council showing a direct cause-and-effect relationship. Building on this foundation, I will introduce a **Socio-Ecological framework** using a multi-level framework to comprehensively analyze the barriers and facilitators that will influence the advancement of Astropharmacy and the operationalization of the Space Pharmacy Council.

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By addressing these issues holistically, we can establish the foundation for the sustainable growth of this emerging field (Astropharmacy).

Evolving role of pharmacists

As the field of space exploration progresses, Astropharmacy is emerging as an essential area of focus within the pharmaceutical sciences[6, 7]. Long-duration spaceflights[8, 9], including missions to Mars and lunar bases, present unique pharmaceutical challenges that require highly specialized space knowledge and skills. Astronauts and their team will need assurance that they have reliable access to safe and effective medications, but conditions in space—such as microgravity[10], radiation exposure[3], and limited medical resources[11]—can significantly impact drug stability and efficacy[6]. These challenges underscore the growing demand for pharmacists who are trained to address the unique healthcare needs of astronauts. Current pharmacy education does not sufficiently prepare pharmacists for the complex scenarios they may encounter in space environments[7]. As a result, it is imperative to expand pharmacy education to encompass space-related competencies, equipping pharmacists to support astronaut health and mission success.

Pharmacy practice without space pharmacy education: Limitations in scope

Currently, pharmacists trained solely in conventional practices can face significant limitations when addressing the pharmaceutical needs in space missions. As awareness of the topic grows, the need for this education becomes more apparent. While pharmacists possess in-depth knowledge of medication management and patient care in terrestrial environments, they lack the specialized education necessary to navigate the complexities of space-related health issues[7]. For instance, the pharmacokinetics and pharmacodynamics of drugs can change drastically in a microgravity environment, impacting their efficacy and safety[6, 12-14]. Without space pharmacy education, pharmacists may find themselves unprepared to tackle such unique challenges, which can have dire consequences for astronaut health and mission success. This gap in knowledge not only restricts their professional growth but also limits the ability to contribute meaningfully to interdisciplinary teams tasked with ensuring the health and safety of astronauts.

Pharmacist with space pharmacy education: Beyond the horizons

In contrast, pharmacists who receive space pharmacy education are equipped with the skills needed to manage and mitigate the challenges associated with space travel. They learn to develop stable medications that can withstand the conditions of space, as well as how to adapt existing treatments for use in a zero-gravity environment. Moreover, understanding the physiological changes that occur in astronauts—such as fluid redistribution[15], muscle atrophy[16], and altered drug metabolism[14]—can enable these pharmacists to play a crucial role in promoting astronaut health. This expanded scope of practice not only enhances their professional capabilities but also opens up new career opportunities in space agencies, research institutions, and academia. By training pharmacists to address these unique challenges, we can ensure a robust healthcare system for future space exploration.

The Teeter-Totter Model: A balanced approach

The Teeter-Totter Model in **Figure 1** serves as a metaphor for balancing the traditional education pharmacists receive with the emerging demands of space pharmacy. On one side (**left side**), we have the pharmacist without space education, represented by a downward tilt in the model, indicating a lack of preparedness for the unique challenges of space. This imbalance highlights the risks associated with neglecting the evolving landscape of pharmacy practice. On the opposite side (**right side**), the pharmacist with space education stands high and ready to adapt to future needs, demonstrating how this education can elevate their practice. The pivot point of the model represents the equilibrium that must be achieved to prepare pharmacists for the future of healthcare in space. Achieving this balance is crucial not just for individual pharmacists but for the pharmaceutical profession as a whole.

Why this balance is crucial for the future?

As we look to the future, the integration of space pharmacy education into existing pharmacy programs becomes increasingly important. The advancement of space exploration necessitates a re-evaluation of pharmacy education to prepare pharmacists for their evolving role in this field. The importance of space pharmacy extends beyond mere academic curiosity; it is essential for the safety and efficacy of healthcare in space environments. By fostering this balance between traditional and space pharmacy education, we can ensure that pharmacists are equipped to contribute meaningfully to the health and well-being of astronauts during space missions.

Expanding scope of space pharmacy education

There is a need to expand space pharmacy education beyond pharmacists to ensure comprehensive preparedness for space healthcare challenges. Educational courses could be developed to reach a broader audience, including space medicine professionals, academics, astronauts, and the general public interested in space traveler safety. Space medicine

professionals, such as physicians and biomedical engineers, would benefit from specialized courses that integrate pharmaceutical care into astronaut health management. Academic researchers studying drug stability, pharmacokinetics, and radiation effects on medications in space environments require targeted training to advance pharmaceutical innovations for long-duration missions. Astronauts and space mission teams need practical education on medication storage, administration, and emergency pharmaceutical interventions to ensure self-sufficiency in space healthcare. Additionally, public outreach initiatives can raise awareness of space pharmacy's role in space exploration, fostering engagement and support for future advancements. By extending space pharmacy education to diverse stakeholders, we can enhance interdisciplinary collaboration, strengthen astronaut healthcare, and promote the sustainable development of Astropharmacy as a vital field in human spaceflight. The Space Pharmacy Council can play a crucial role in expanding space pharmacy education by developing standardized curricula, fostering collaboration among disciplines, and ensuring the integration of pharmaceutical expertise into space healthcare initiatives.

If-Then Logic Model for the Space Pharmacy Council

The **If-Then Logic Model** in the **Figure 2** for the Space Pharmacy Council (**see supplementary information**) offers a structured framework that outlines a clear sequence of actions and anticipated outcomes to guide the development of Space Pharmacy Council as an organized and recognized field. In the diagram, a process illustrating how combining two key inputs (**Input X and Input Y**) leads to a desired outcome. Input X and Input Y represent essential elements, such as resources, conditions, participation, research or actions, that must work together for the process to succeed. The "+" symbol signifies their integration, emphasizing that both inputs are necessary for the system to function effectively. The "=" symbol connects this integration to the final result, showing a direct cause-and-effect relationship. The forward-moving arrow highlights the linear progression from inputs to outcome, symbolizing growth or achievement. This model provides a logical and clear framework for planning and executing processes in research, education, or other fields where collaboration and resource alignment are critical for success. By focusing on "If-Then" propositions, this model provides a predictive structure that enables a systematic approach to building the field of Astropharmacy and ensuring the consistent preparation of pharmacists to support human health in space missions. The explanation of each step in the model is as follows:

Step 1: Establishment of the Space Pharmacy Council

If a Space Pharmacy Council is established with the primary mission of standardizing space pharmacy guidelines and professional requirements for pharmacists preparing for space missions, **Then** this council can develop specialized training programs, certifications, and educational frameworks tailored

to the unique needs of space pharmacists. The creation of a Space Pharmacy Council is the foundational step in the **If-Then Logic Model**. This council would act as the central body governing the standards, competencies, and guidelines necessary for space pharmacy practice and advisory council for drugs in space travel. It would be composed of experts in pharmaceutical sciences, space medicine, regulatory bodies, and leaders from space research organizations such as National Aeronautics and Space Administration (NASA), European Space Agency (ESA), United Nations Office for Outer Space Affairs (UNOOSA) and private companies engaged in space exploration. The responsibilities of the council would include:

- Standardizing educational and training requirements to ensure that pharmacists, astronauts, researchers and medical doctors gain knowledge specific to the challenges of space.
- Creating a regulatory framework for pharmaceutical care in space, including drug preparation, storage, and distribution.
- Collaborating with space agencies and academic institutions to facilitate research and training partnerships.
- Providing certifications and credentials for pharmacists, or anyone else handling or managing pharmaceuticals or therapies who complete space pharmacy training programs, giving formal recognition to their expertise.

By establishing this council, the field of space pharmacy can be organized under a centralized authority, allowing for the consistent and collaborative development of curricula, professional standards, and research priorities. Without this council, the progression of space pharmacy education and practice would lack direction, risking inconsistency and misalignment with the needs of space missions.

Step 2: Development of specialized programs and certifications

If the Space Pharmacy Council develops specialized programs and certifications for pharmacists, **Then** pharmacists and other healthcare professionals can gain the essential skills and knowledge required to address space-specific pharmaceutical challenges, such as managing drug stability in microgravity and ensuring medication efficacy under radiation exposure. Once the council is established, its primary goal will be development of comprehensive educational programs that address the unique needs of space pharmacy. These programs would be structured to cover both theoretical knowledge and practical skills essential for the unique conditions of space. Key areas of focus might include:

- **Pharmacokinetics and pharmacodynamics in altered gravity[14]:** Understanding how microgravity impacts drug absorption, distribution, metabolism, and excretion is crucial, as the altered physiological

conditions of space can affect the way medications work.

- **Radiation protection[17]:** Prolonged space travel exposes astronauts to high levels of cosmic radiation, which can degrade medications. Pharmacists must be trained in selecting and managing medications that are less vulnerable to radiation or in devising storage solutions or novel formulation to minimize degradation.
- **Drug stability and storage solutions[6]:** Space missions face limited resources and space constraints. Pharmacists must understand drug stability under varying temperatures and storage options for medications to ensure they remain effective for the duration of a mission.

Through certifications, pharmacists will not only validate their specialized knowledge but also receive a formal credential that distinguishes them as space pharmacy experts. This will be critical for assigning pharmacists to missions or for leadership roles in space health programs.

Step 3: Provision of Space-Relevant competencies to pharmacists

If these specialized programs and certifications are made available to pharmacists, **Then** pharmacists will be trained in space-relevant competencies that directly address the pharmaceutical needs of astronauts, such as selecting appropriate medications, managing inventory under restrictive space conditions, and adapting to medical emergencies in space. This step emphasizes the acquisition of practical, space-specific competencies through the training programs established by the council. Beyond theoretical understanding, pharmacists will need hands-on skills and simulation experiences to prepare for real-world application. Training in space-relevant competencies includes:

- **Inventory management:** Space missions have limited space for storing medications[18]. Pharmacists must be skilled in efficiently managing inventory, prioritizing essential medications, and planning for long-term storage.
- **Environmental adaptation:** Pharmacists must be capable of adapting to unpredictable environments. This includes potential shifts in gravity, sudden changes in available resources, and unanticipated medical needs of astronauts.
- **Emergency preparedness:** Training programs would include simulations of medical emergencies in space, preparing pharmacists to manage crises effectively despite limited equipment and resources.

These competencies will enable pharmacists to make critical medication-related decisions that protect astronaut health,

ensure effective medication management, and support the overall success of space missions.

Step 4: Enhanced pharmaceutical care for astronauts

If pharmacists are trained in these space-relevant competencies, **Then** they will be well-prepared to develop, prepare, and administer medications suited for space environments, effectively supporting astronaut health.

The logical outcome of equipping pharmacists with space-relevant skills is the enhancement of pharmaceutical care available to astronauts. Pharmacists trained by the Space Pharmacy Council will have the expertise to:

- **Formulate medications that remain stable and effective in space:** By understanding the effects of space conditions on drug formulations, pharmacists can select and modify medications that meet the demands of space travel.
- **Administer medications in a zero-gravity environment:** Pharmacists trained in space-specific practices will be familiar with the techniques required to safely administer drugs in microgravity, reducing the risk of improper dosing or contamination.
- **Support long-term astronaut health:** Pharmacists will be able to monitor and adapt treatment plans based on the unique physiological changes astronauts experience in space, contributing to better health outcomes and mission success.

This specialized care directly supports astronauts' well-being, reduces risks associated with medication instability or inefficacy, and ensures that mission objectives are met without compromising crew health.

Final Outcome: Sustainable development of Astropharmacy as a discipline

If astronauts have access to reliable, space-tailored pharmaceutical care, **Then** their health and safety are significantly enhanced, reducing the risks of medication-related issues in space and supporting the sustainable expansion of human presence in space. With a robust Space Pharmacy Council guiding the development of training, standards, and research, Astropharmacy will evolve into a well-structured and sustainable discipline. This institutional support is essential for:

- **Ongoing research and innovation:** The Space Pharmacy Council can advocate for and fund research into new drug formulations, alternative therapies, and space-compatible pharmaceutical technologies.
- **Global collaboration:** As space exploration increasingly becomes an international endeavor, the council can foster collaboration across countries, space agencies, and academic institutions to ensure consistent practices and share knowledge.
- **Future-proofing space missions:** By preparing a pipeline of trained space pharmacists, the Space

Pharmacy Council ensures that as space missions grow in complexity and duration, there will always be qualified professionals available to address the pharmaceutical needs of astronauts.

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To summarize, **If-Then Logic Model** for the Space Pharmacy Council lays out a clear and systematic path for advancing Astropharmacy, from establishing a regulatory body to equipping pharmacists with the skills they need to support human health in space. This model highlights the necessity of structured education and training, specialized competencies, and ongoing support from a governing council to ensure that space pharmacists are well-prepared for the challenges of space missions.

Socio-Ecological Framework: Barriers and facilitators to Space Pharmacy Council

Astropharmacy is an emerging domain[6]. Despite its potential, it can face challenges in establishing itself as a recognized discipline. Issues such as the absence of standardized guidelines, limited research infrastructure, and a lack of specialized training programs underscore the need for innovative strategies to promote its development. The **Socio-Ecological model (Figure 3)** is a multi-level framework provides a robust framework for analyzing these challenges across multiple levels. It highlights four levels: **Individual, Interpersonal, Organizational, and Cultural**, each addressing unique challenges and opportunities for the advancement of Astropharmacy.

1. Individual level

At the foundation of the socio-ecological model lies the individual level, focusing on the knowledge, skills, and attitudes of pharmacists.

Barriers:

- **Lack of awareness:** Many pharmacists are unaware of Astropharmacy as a career path. This lack of exposure limits interest in the field, reducing the pool of professionals willing to engage in space-specific pharmaceutical research and practice. Without visibility, the field risks remaining an academic curiosity rather than a practical profession.
- **Insufficient knowledge and training:** Space missions pose unique pharmaceutical challenges, including drug stability in microgravity, radiation effects on medications, and the development of personalized treatment plans for astronauts. Traditional pharmacy education does not cover these aspects, leaving most pharmacists unprepared for this domain.
- **Cost barriers:** Specialized education, such as Astropharmacy certification courses or advanced training, often requires substantial financial investment. The lack of scholarships and funding

opportunities further discourages participation, especially from individuals in low-resource settings.

Facilitators:

- **Targeted education programs:** Developing affordable, accessible training programs, such as online courses and workshops, can bridge knowledge gaps. Modules focusing on drug degradation in microgravity, radiation pharmacology, and space medicine can be introduced.
- **Scholarships and funding:** Offering scholarships or financial aid to aspiring space pharmacists will reduce economic barriers and encourage greater participation, particularly from underrepresented regions.
- **Role models and success stories:** Promoting the achievements of pioneers in Astropharmacy can inspire pharmacists to pursue this field. Success stories create a vision of possibility and generate enthusiasm within the profession.

2. Interpersonal level

The interpersonal level examines the relationships between individuals and teams, highlighting the importance of collaboration and communication.

Barriers:

- **Limited interprofessional, multidisciplinary collaboration:** Astropharmacy requires close collaboration between pharmacists, aerospace engineers, physicians, and other specialists. However, these disciplines often operate in silos, creating barriers to effective teamwork.
- **Communication gaps:** The lack of shared terminology and mutual understanding between pharmacists and other space mission stakeholders impedes effective planning and execution of pharmaceutical care in space.
- **Resistance from educators:** Traditional pharmacy educators may be hesitant to integrate space-focused topics into already packed curricula. This resistance further delays the mainstreaming of Astropharmacy education.

Facilitators:

- **Cross-disciplinary training:** Developing programs that bring pharmacists, engineers, and other medical professionals together can foster collaboration. Interdisciplinary case studies and simulation exercises can strengthen mutual understanding and teamwork.
- **Networking opportunities:** Conferences, webinars, and think tanks focusing on Astropharmacy can provide platforms for sharing knowledge, building professional relationships, and exploring collaborative projects.

- **Working groups:** Forming dedicated working groups within professional organizations can advocate for Astropharmacy and provide resources for those interested in the field. These groups can also serve as advisory bodies for policymakers and space agencies.

3. Organizational level

Organizations play a crucial role in providing resources, infrastructure, and policy support for Astropharmacy.

Barriers:

- **Lack of institutional support:** Few institutions prioritize Astropharmacy, leaving researchers without the infrastructure or resources needed to advance the field.
- **Funding deficits:** Research in Astropharmacy is often sidelined due to competing priorities. Without dedicated funding streams from space agencies, pharmaceutical companies, or academic institutions, progress remains slow.
- **Curricular exclusion:** Most pharmacy programs do not include Astropharmacy topics, leaving students unaware of the field's potential or the skills required to succeed in it.

Facilitators:

- **Specialized research centers:** Establishing research centers dedicated to Astropharmacy can provide the infrastructure and focus needed to drive innovation. These centers can also serve as hubs for training and education.
- **Funding initiatives:** Securing grants from space agencies like NASA and ESA, as well as partnerships with pharmaceutical companies, can ensure sustained financial support for Astropharmacy research and education.
- **Curricular integration:** Including Astropharmacy as part of pharmacy school curricula can create a pipeline of trained professionals. Topics such as space pharmacology, drug stability, and mission-specific pharmaceutical care can be introduced as electives or core modules.

4. Cultural level

The cultural level examines societal attitudes, norms, and values that influence the acceptance and advancement of Astropharmacy.

Barriers:

- **Limited recognition:** The role of pharmacists in space missions is often overlooked, both by the public and other space mission stakeholders. This lack of recognition reduces the perceived importance of the field.

- **Resistance to change:** Within the broader pharmacy community, there has been resistance to adopting new practices or embracing emerging fields like Astropharmacy.
- **Perceived impracticality:** Some stakeholders may view Astropharmacy as a niche or impractical discipline, further discouraging investment and support.

Facilitators:

- **Public awareness campaigns:** Highlighting the contributions of pharmacists to space exploration through media campaigns can build public and professional recognition.
- **Advocacy by professional organizations:** Pharmacy organizations can play a pivotal role in legitimizing Astropharmacy by advocating for its inclusion in policy discussions and funding priorities.
- **Culture of innovation:** Encouraging a mindset of adaptability and innovation within pharmacy practice can help overcome resistance to change. This can be achieved through continuous professional development and exposure to cutting-edge research.

The socio-ecological approach underscores the need for targeted interventions at multiple levels to overcome barriers and leverage facilitators. The proposed Space Pharmacy Council in my previous letter can serve as a unifying body to address these challenges systematically[5]. By fostering collaboration, securing funding, and promoting education, the council can accelerate the development of Astropharmacy and prepare pharmacists for their critical roles in space exploration.

Conclusion

In conclusion, the advancement of Astropharmacy is not just a future necessity but an urgent imperative for the success of long-term space exploration. The Teeter-Totter Model, If-Then Logic Model, and Socio-Ecological Approach each provide invaluable insights into how we can address the barriers to space pharmacy education, and ultimately, how we can prepare pharmacists to meet the unique demands of space missions. The establishment of a Space Pharmacy Council is critical in setting the standard for education, fostering multidisciplinary collaboration, and ensuring a future where pharmacy plays a indispensable role in astronaut health and mission success. By integrating these models and building upon them, we can transform space pharmacy from a conceptual discipline into a robust and essential component of space exploration.

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Conflicts of Interest: None

Supplementary information:

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Figure 1: Teeter-Totter Model for understanding the importance of Space Pharmacy education

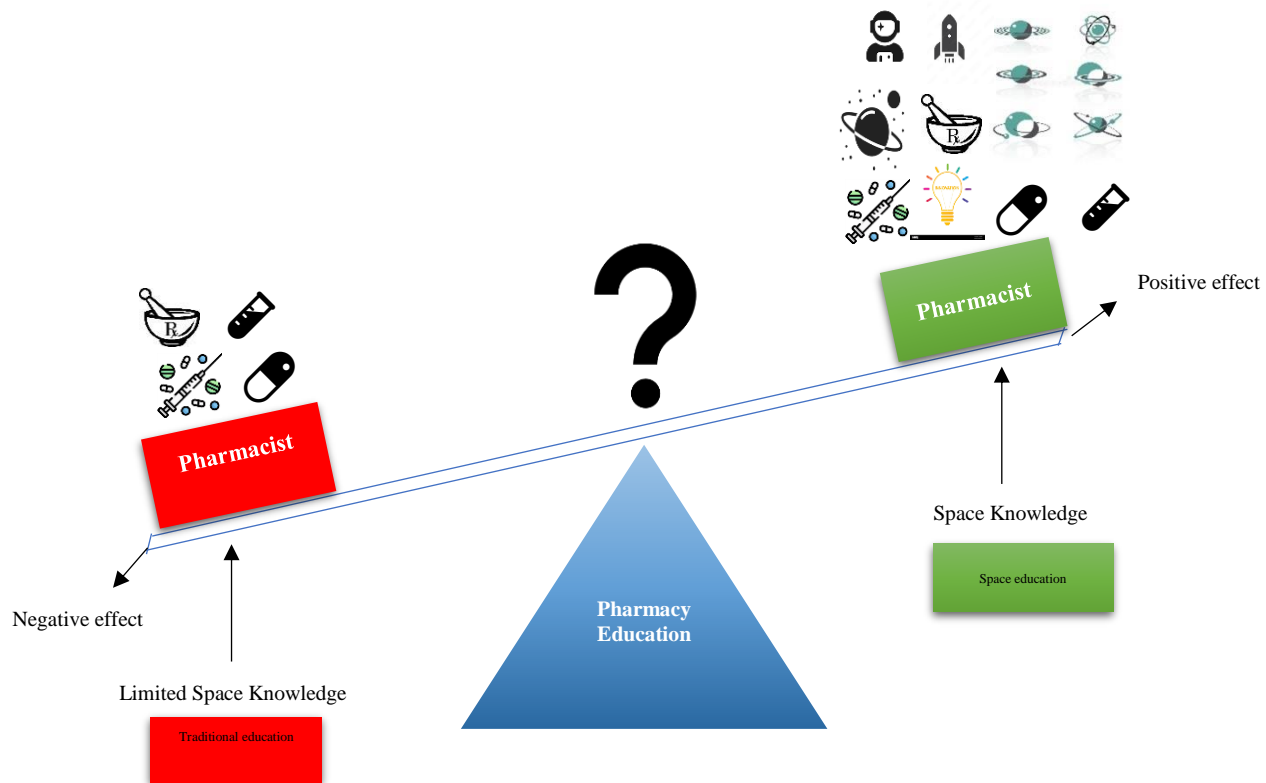


Figure 2: If-Then Logic Model for Space Pharmacy Council

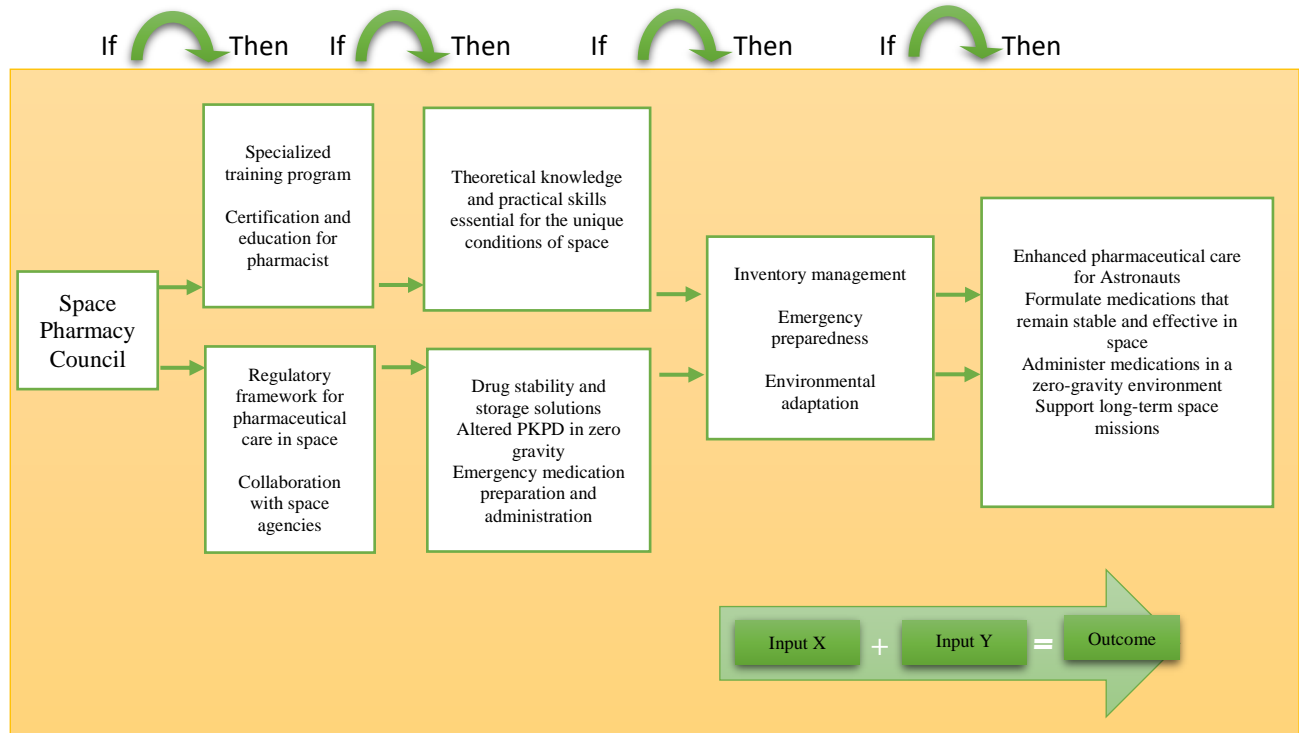


Figure 3: Socio-Ecological Framework for understanding barriers and facilitators to Astropharmacy