STUDY OF SPACE EDUCATION ACTIVITIES AND EDUCATIONAL EVALUATION METHODS USING INTERNATIONAL COLLABORATIVE STRATOSPHERIC BALLOON EXPERIMENTS

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Mongolia spans a vast east–west distance, with its eastern regions characterized by flat terrain and sparse population. These geographical features make it particularly suitable for stratospheric balloon experiments. In addition, radio communication for academic purposes is permitted, the Mongolian aviation authorities are supportive of such activities, and the general public maintains a favorable disposition toward Japan. Leveraging these advantages, we have conducted stratospheric balloon experiments in Mongolia since 2016, in collaboration with the Institute of Engineering and Technology (IET), Mongol Koosen College of Technology (MKCT), and the Mongolian University of Science and Technology (MUST).

Building upon these efforts, we are developing space education programs in both Japan and Mongolia that incorporate stratospheric balloon experiments as core instructional tools. While multiple definitions of space education exist, we define it in this context as educational activities conducted under the theme of space exploration and technology.

In Japan, two initiatives have been jointly implemented in Ehime Prefecture since September 2022: a stratospheric balloon experiment program for university students and the "Stratospheric Balloon Koshien" competition for high school and technical college students. Furthermore, since 2023, a joint international project involving university and college of technology students from Japan and three Mongolian KOSENs—MKCT, New Mongol College of Technology (NMCT), and MUST-Kosen College of Technology (MUST-KCT)—has been in operation.

The stratosphere, the operational domain of these balloons, presents extreme environmental conditions, with atmospheric pressure reduced to approximately 0.5% of sea-level values and temperatures reaching −50°C. Designing mission equipment capable of functioning under such conditions, managing multidisciplinary project teams, and executing flight operations to successful completion parallels the challenges encountered in actual spacecraft development. As such, stratospheric balloon experiments provide significant educational value within the context of space education.

This paper presents the potential of stratospheric balloon experiments as a sustainable and scalable space education platform through international collaboration[1][2]. It also explores an approach for educational assessment using rubric-based evaluation methods.

Keywords: *Stratospheric Balloon, Space Education, Engineering Education, International Cooperation, PBL*

Introduction

When a helium-filled rubber balloon is released, it ascends continuously due to buoyant force. As it rises, the atmospheric pressure decreases, causing the balloon to expand. At an altitude of approximately 30 km, the balloon bursts due to overexpansion. The payload then descends gradually using a parachute and eventually lands on the ground. Throughout the flight, onboard cameras and electronic instruments conduct observations and experiments. This process is referred to as a stratospheric balloon experiment.

Since 2016, we have been conducting stratospheric balloon experiments in collaboration with the Mongolian University of Science and Technology and the Mongolian National College of Technology. A total of 40 experiments have been completed, all of which successfully recovered the onboard equipment. In 2019, permission was obtained from the Mongolian Civil Aviation Authority to regularly submit NOTAMs and utilize a portion of the airspace above Ulaanbaatar for balloon launches. As part of public outreach, a commemorative experiment was organized in 2019, in which three balloons were launched sequentially from Sukhbaatar Square to celebrate the 380th anniversary of Ulaanbaatar. Technical support was provided to ensure the safe and reliable execution and retrieval of the balloons.


Figure 1. Stratospheric balloon experiment in Mongolia

Materials and Methods

Building on these achievements, we investigated the application of stratospheric balloon experiments in space education. Space education broadly encompasses two categories: one involves using knowledge, technology, and data obtained from actual space missions; the other aims to foster human resource development through simulated space experiences. This study focuses on the latter. Hybrid rockets and CanSats are frequently utilized in such educational contexts. Hybrid rockets are student-built and launched to altitudes of several kilometers, while CanSats emulate satellite behavior by collecting and processing data via sensors and controllers. These hands-on projects are designed to enhance student engagement and foster non-cognitive skills such as problem-solving, project management, and teamwork.

In Japan, student-led stratospheric balloon experiments have been conducted since approximately 2013. With the advancement and miniaturization of electronic components, such experiments have become increasingly accessible. Additionally, public interest has grown due to media exposure, encouraging student participation. However, challenges remain, including the need to navigate regulatory procedures and the absence of a shared technical knowledge base.

Japan’s geographic characteristics, such as limited landmass and surrounding oceans, pose additional difficulties in recovering balloon payloads. When equipment is lost at sea, valuable data and imagery cannot be retrieved, compromising the educational value of the simulated space experience. To address this issue, we aimed to establish a structured educational framework enabling students to successfully recover payloads based on our experimental success in Mongolia.

Technical guidance was provided to students to ensure accurate prediction and retrieval of balloon payloads. We employed the Cambridge University Spaceflight Landing Predictor[3], which requires parameters such as launch coordinates, altitude, date and time, ascent rate, burst altitude, and descent speed. Balloon ascent rate, a key input, is influenced by the amount of helium injected and the payload mass. Helium volume was calculated using spreadsheets developed during previous experiments in Mongolia. As upper-atmospheric wind conditions are unpredictable beyond 180 hours in advance, trajectory predictions are subject to periodic revision based on weather updates.

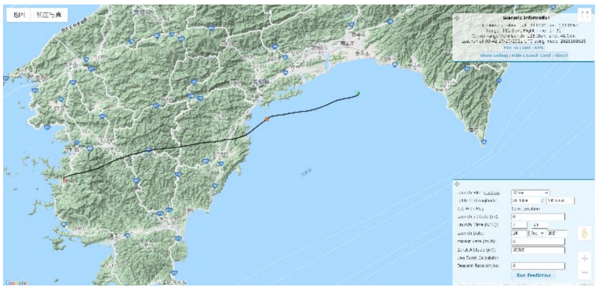
Figure 2. Stratospheric balloon flight path simulation

Reliable communication systems are essential for payload tracking and recovery. GPS devices onboard collect positional data, which is transmitted via communication modules. Past failures in student projects were often due to communication malfunctions. To mitigate this risk, students were instructed to install redundant communication systems and perform environmental and performance tests, including low-temperature, long-range, and endurance tests on the ground.

Following technical instruction, three stratospheric balloon experiments were conducted in Japan in 2021: in Kuroshio Town (Kochi Prefecture), Itoshima City (Fukuoka Prefecture), and Uwajima City (Ehime Prefecture). All payloads were successfully recovered. For the Fukuoka mission, the balloon was launched 10 km offshore from Itoshima City based on trajectory predictions to capture stratospheric images.

To facilitate ongoing experimentation, a permanent balloon environment was established near Uwajima City and Ainan Town. Beginning in 2022, two educational initiatives are held annually: the Stratospheric Balloon Joint Experiments for university students and Stratospheric Balloon Koshien for high school and technical college students. These initiatives enable participants to engage in comprehensive or introductory-level balloon activities, respectively.

Joint experiments are a collaborative model used in other space education contexts. They allow teams with limited resources to conduct experiments in cooperation with other organizations. This model helps students develop essential collaborative skills such as coordination, negotiation, and project management. In the joint stratospheric balloon experiment, university students are responsible for all aspects, including equipment development, gas injection, flight operations, tracking, recovery, and coordination with authorities and local communities.

Balloon Koshien provides an introductory experience with minimal restrictions, encouraging creativity in payload design. Participants are only required to develop their observation equipment. After the experiment, each participant evaluates and reports on their mission, with assessments conducted by an external jury.

Figure 3. Stratospheric balloon experiment at sea in Itoshima City, Fukuoka Prefecture

To ensure experiment safety, a panel of experts was established, including engineers from JAXA and private balloon companies. Participating teams must undergo a third-party safety review before conducting experiments. The review process includes ICAO-compliant airspace regulations[4], parachute drop tests, buoyancy checks, communication and long-run tests, and confirmation of the actual flight hardware at the site. This framework mirrors that of hybrid rocket launch safety reviews.

Based on the results from Japan, a joint project was launched involving Japanese and Mongolian students. Participants included teams from Japanese universities and Mongolian KOSENs such as Mongol Koosen College of Technology (MKCT), New Mongol College of Technology (NMCT), and MUST-Kosen College of Technology (MUST-KCT). Annual joint experiments have been held since 2023, following preparatory lectures delivered at each Mongolian KOSENs. After the project team was established, students in Japan and Mongolia shared information using online tools and held regular online meetings to prepare for the experiments.

Figure 4. Preparation work for stratospheric balloon experiment in Mongolia

Japanese university students led the overall project, including equipment development and flight path prediction. Technical college students from both countries contributed to payload development. Assigning clear roles within international project teams helped facilitate successful implementation and enhanced educational impact.

Post-experiment debriefings were held in Ulaanbaatar, where teams presented their findings and engaged in discussions. These sessions were conducted as part of the International Space Balloon Summit[6] organized by MARSA[5] and were attended by students, industry stakeholders, and government representatives, including officials from the Mongolian Civil Aviation Authority.

Figure 4. Japan-Mongolia Stratospheric Balloon Joint Experiment

Figure 5. Japan-Mongolia Stratospheric Balloon Joint Experiment Results Debriefing

To evaluate the educational methodology based on a series of stratospheric balloon experiments, we conducted a structured analysis of the competencies that students are expected to acquire through participation in such projects. Five core competency domains were defined as the learning objectives of the program. For each domain, detailed evaluation criteria were established as follows:

A) Ability to independently design a mission utilizing a stratospheric balloon

1. Setting and defining mission objectives
2. Identifying technical or societal challenges
3. Formulating specific mission goals and deliverables
4. Assessing feasibility in terms of technical, financial, and temporal constraints

B) Ability to explain the processes and requirements necessary for conducting a stratospheric balloon experiment
1. Understanding and articulating the experimental workflow
2. Identifying required resources, equipment, and personnel
3. Developing an appropriate schedule for implementation

C) Ability to solve complex problems through project management in stratospheric balloon experiments
1. Monitoring project progress and making necessary adjustments
2. Prioritizing tasks and allocating resources accordingly

D) Ability to work collaboratively and harmoniously with diverse individuals through international and domestic project participation
1. Understanding and adapting to different cultures
2. Building constructive relationships with team members

E) Ability to transfer knowledge and lessons learned from the stratospheric balloon experiment to future generations
1. Organizing and reproducing knowledge for dissemination
2. Providing constructive feedback and proposing areas for improvement

In addition, a rubric was created for the achievement level of each detailed evaluation item with a 5-point scale (5 being the highest and 1 being the lowest), and the students were asked to self-evaluate before and after the experiment was conducted.

Results and Discussion

A rubric evaluation was conducted on a trial basis during the Japan-Mongolia stratospheric balloon joint experiment in March 2025. The results are shown below.

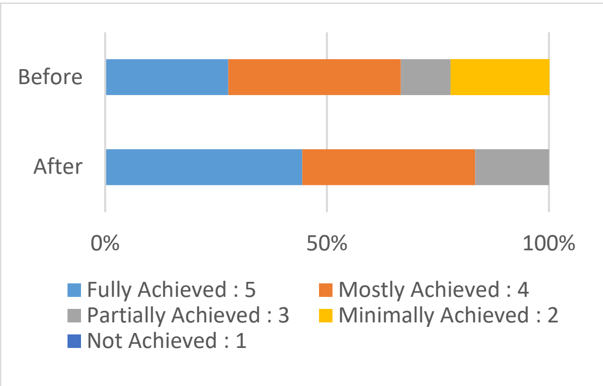

Figure 6. Pre-post evaluation of rubric assessment item A)-1

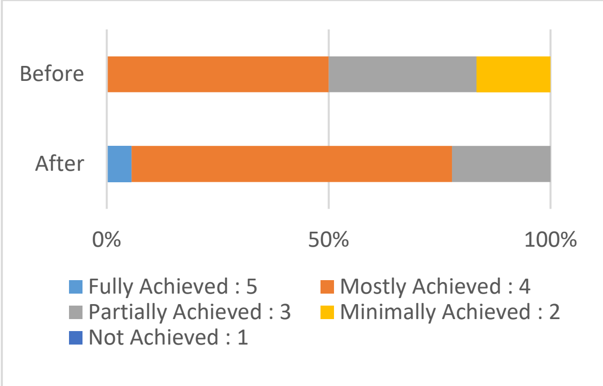

Figure 7. Pre-post evaluation of rubric assessment item A)-2

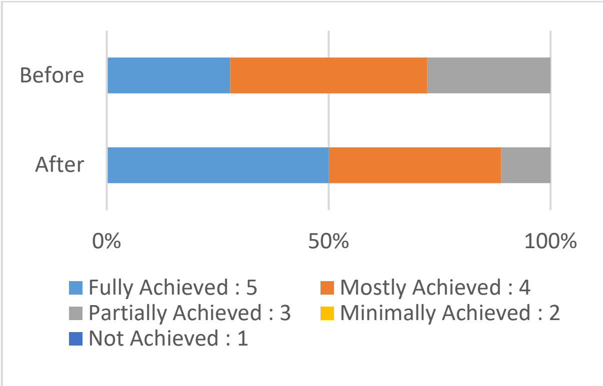

Figure 8. Pre-post evaluation of rubric assessment item A)-3

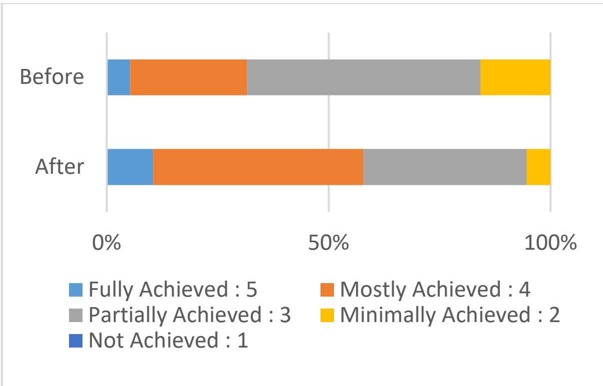

Figure 9. Pre-post evaluation of rubric assessment item A)-4

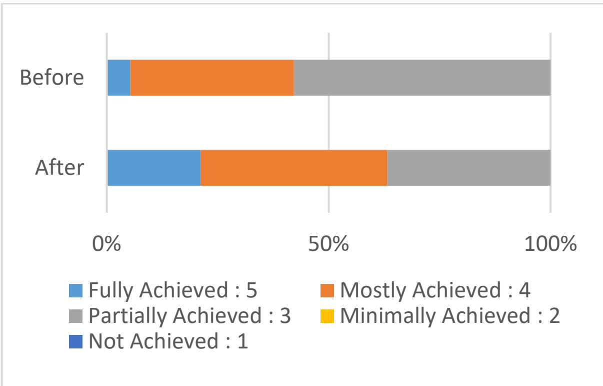

Figure 10. Pre-post evaluation of rubric assessment item B)-1

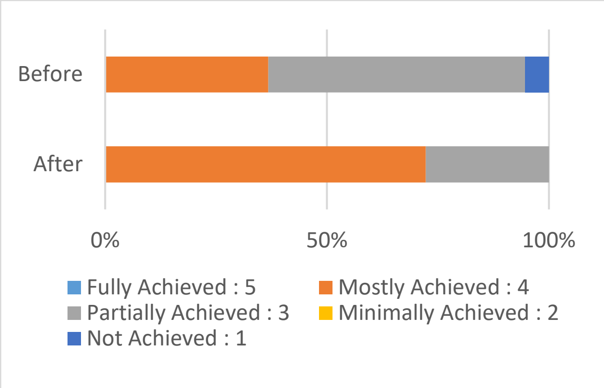

Figure 11. Pre-post evaluation of rubric assessment item B)-2

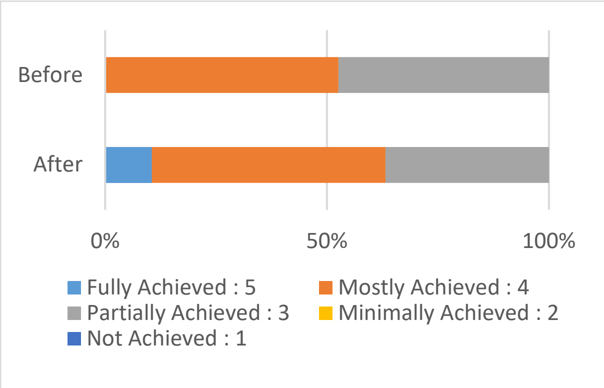

Figure 12. Pre-post evaluation of rubric assessment item B)-3

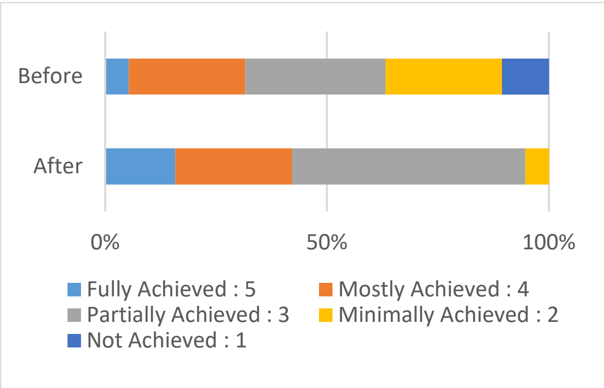

Figure 13. Pre-post evaluation of rubric assessment item C)-1

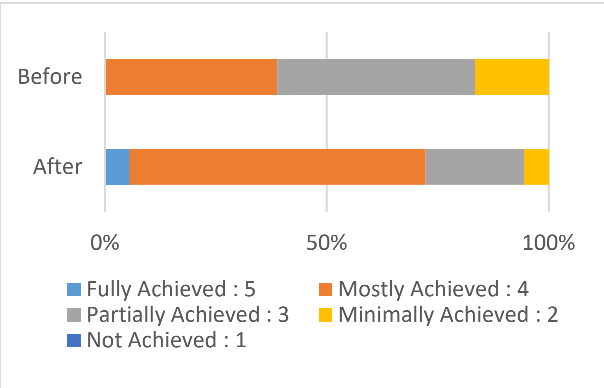

Figure 14. Pre-post evaluation of rubric assessment item C)-2

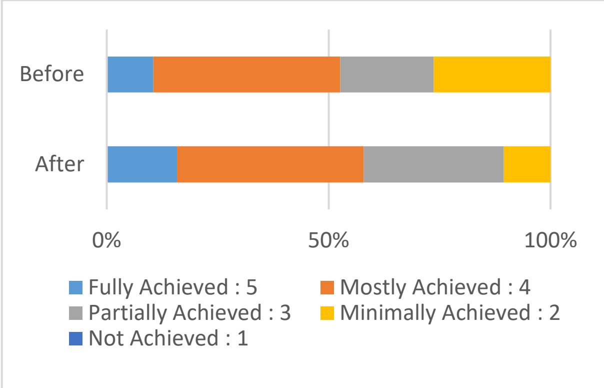

Figure 15. Pre-post evaluation of rubric assessment item D)-1

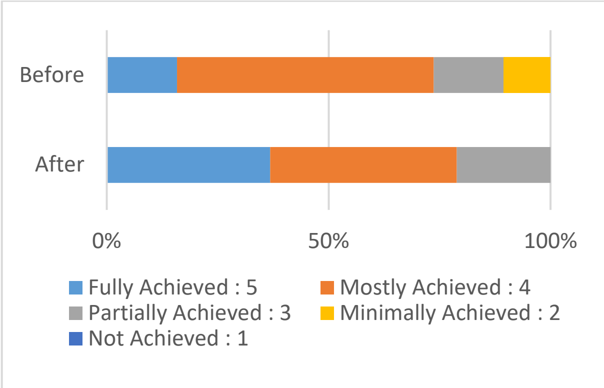

Figure 16. Pre-post evaluation of rubric assessment item D)-2

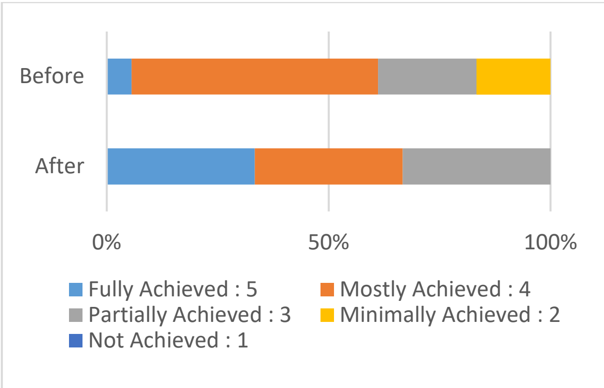

Figure 17. Pre-post evaluation of rubric assessment item E)-1

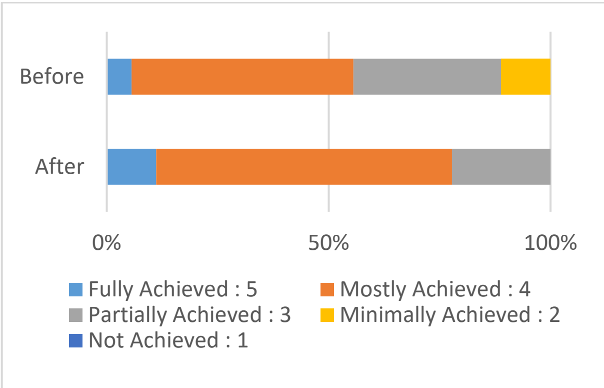

Figure 18. Pre-post evaluation of rubric assessment item E)-2

The following table shows the change in average scores and the difference in each detailed evaluation item assessed before and after the experiment. There were 18 participants in this project. Furthermore, a t-test was conducted with a significance level of 0.05, and it was confirmed that all items showed significant differences. Additionally, the results of the effect size calculation using Hedges' g are also included.

Table 1. Changes in mean scores in rubric evaluation before and after stratospheric balloon experiment

Item	Before / After	Avg.	Diff.	p-value	g
A)-1	Before	3.72	0.56	<0.05	0.67
	After	4.28			
A)-2	Before	3.33	0.50	<0.05	0.67
	After	3.83			
A)-3	Before	4.00	0.39	<0.05	0.74
	After	4.39			
A)-4	Before	3.17	0.50	<0.05	**0.92**
	After	3.67			
B)-1	Before	3.50	0.33	<0.05	0.65
	After	3.83			
B)-2	Before	3.17	0.56	<0.05	**1.03**
	After	3.72			
B)-3	Before	3.44	0.39	<0.05	0.74
	After	3.83			
C)-1	Before	2.94	0.61	<0.05	**0.96**
	After	3.56			
C)-2	Before	3.22	0.50	<0.05	0.67
	After	3.72			
D)-1	Before	3.33	0.44	<0.05	**0.83**
	After	3.78			
D)-2	Before	3.89	0.33	<0.05	0.65
	After	4.22			
E)-1	Before	3.50	0.50	<0.05	**0.92**
	After	4.00			
E)-2	Before	3.50	0.39	<0.05	0.61
	After	3.89			

Conclusions

Based on t-tests of the rubric evaluation, we conclude that the program is effectively meeting our expectations. Additionally, we assessed the effect sizes using Hedges' g and identified several items with 'large effects' ($g \geq 0.8$). The educational effects of the program on five items, A)-4, B)-2, C)-1, D)-1, and E)-1, are significant. In particular, "C)-1: Monitoring project progress and making necessary adjustments" is a skill that can only be developed through such project activities. "E)-1: Understanding and adapting to different cultures" is an ability that could only have been developed through this project, which was conducted jointly by Japanese and Mongolian students. These are the educational effects we expected. In the future, we would like to continuously measure the educational effects by further subdividing the evaluation items of this rubric and scrutinizing them.

On the other hand, there are several problems with this initiative. The transfer of skills and know-how among the participating students of different ages is often not smooth. This is a problem unique to student project activities in which the students' grades increase as they get older. It is necessary to take countermeasures such as consolidating technology and know-how across participating organizations, handing over the technology and know-how among the different age groups, and holding regular technical seminars.

Regarding experiments in Mongolia, the "language barrier" between Japanese and Mongolian students hinders smooth communication. Both students often communicate in English, which is not their native language, but they are often unable to understand each other in terms of detailed differences in nuances. This may cause serious accidents in emergency situations during experiments, and immediate action is needed. It is necessary to prepare manuals in Japanese, English, and Mongolian on how to operate equipment, procedures, emergency response methods, evacuation routes, etc., during experiments, to ensure a common understanding.

While solving these issues, we would like to continue space education activities using stratospheric balloon experiments in Japan and Mongolia, and evaluate the effectiveness of the education using rubric evaluation.

Acknowledgements

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