Three-year Achievements in Human Resource Development Program in Space Engineering

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In this paper, we report an achievement of Human Resource Development Program for student of National Institute of Technology (KOSEN). This program is aimed to cultivate an ability of the aerospace engineering in non-space major students. The program consists of three parts of sub-programs: (1) KOSEN Space Academia which is a remote hands-on seminar using video conference system (2) KOSEN Space Camp which is a four-days camp-style workshop held in Niihama city, and (3) KOSEN-1 project which is an actual development of 2U size CubeSat. A total of 263 students and 78 faculty members participated in this program for three years from 2017 to 2019.

Key Words: CubeSat, Hands-on workshop, Human Resource Development

1. Introduction

Since the successful launch of the first CubeSat in 2003, many educational programs have been conducted to apply CubeSat development to actual education of aerospace engineering. [1-5)] In general, the satellite bus system includes the several subsystems which are power, communication, thermal control, structure, data handling etc. Each subsystem can be applied to general engineering education as an independent field. Students are required to develop these subsystems so that they work in complex and cooperative manners. This concept leads the CubeSat into the engineering education not only for the aerospace engineering but for more general engineering fields.

National Institute of Technology (hereafter referred to as KOSEN)[6)] have been promoting practical engineering education required by industries, focusing on extremely practical educational programs compared to the other institutions of higher education. We established the "KOSEN Space Collaboration Group" in 2011, which is a consortium of faculty members who specialize in space engineering and/or space sciences, and who aim to expand their expertise to engineering education. Currently, more than 30 faculty members are participating this consortium and exchanging their knowledge of education and research.

From 2014 to 2016, the "KOSEN Space Collaboration Project for Space Human Resource Development toward the Actual Development of the CubeSat" was funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT) and was conducted mainly by the faculty members of this KOSEN space collaboration group. In this project, we aimed to develop two CubeSats for the first time as KOSEN, and to cultivate students who can participate in the satellite development project. Students from KOSENs all over the country have participated in activities such as the KOSEN Space Camp and the KOSEN Rocket and CanSat Contest to learn the basics of satellite systems, and several students had also participated in the actual CubeSat development through satellite design contests and graduation research.

Through the above project, it became clear that the development of contents for engineering education using satellites is an extremely useful even for national KOSEN that do not have specialized departments in aerospace engineering. On the other hand, the environment surrounding engineering education has been changing drastically in the past three years, and we have been discussing the next process to improve the program based on the achievement of the above three years program. In this paper, based on the results of the space human resources development program that has been implemented until 2016, we will implement the new initiatives described below to develop a "network-type" space human resources development program that can be applied to various specialized fields for students up to the bachelor's level, not only in KOSEN but also in the other higher education institutions that have no specialized departments in aerospace engineering.

2. Educational programs for beginners toward an actual CubeSat development

In this program, we developed two individual sub-programs for the KOSEN students with no previous education in aerospace engineering. One is the KOSEN Space Academia, which consists of some lectures and hands-on workshops conducted by using a remote-conference system. Another is the KOSEN Space Camp, which is a training-camp-style seminar held at Niihama city once a year.

2.1. The KOSEN Space Academia

The KOSEN Space Academia is a framework for conducting lectures and hands-on training for KOSEN students who are interested in the field of aerospace engineering, by using online conference system. Faculty members played the role of lecturers and trainers in this Space Academia. In each KOSEN, the students received information and teaching materials through the faculties assigned as a tutor. To conduct the online conference, we mainly used the software of Skype for Business, which was available to faculty members of KOSEN. In addition, the collaborating KOSEN had overseen the development, preparation, and delivery of teaching materials.

Fig. 1. The leaflet of the KOSEN Space Academia. From the left to right, the kick-off meeting 2017, Space Academia 2018 and 2019, respectively.

The main activities were the kick-off meeting in 2017, Space Academia 2018, and 2019. Fig 1 shows the leaflet. Participants were students from many KOSENs all over Japan. 15 students participated in the kick-off meeting 2017, 69 students in Space Academia 2018, and 111 students in Space Academia 2019. The number of participants is summarized in Table 1. In each case, it was an effort to further develop the characteristics of KOSEN students by combining online lectures and manufacturing practice. The program was designed to fucus on the hands-on workshop using the teaching materials to learn about the basic function of the On-Board Computer (OBC). The students needed to struggle to build this teaching material and understand how to operate the satellite bus-system and to handle the data. To effectively implement above stated point, the facilitator prepared the instruction materials in advance.

Table 1. Number of participants for the KOSEN Space Academia.

FY	KOSENs	Students	Faculties
2017	10	15	13
2018	13	69	16
2019	19（20 Campus）	111	21
Total	42	195	50

2.2. The KOSEN Space Camp

The KOSEN Space Camp was held in Niihama city for four days to conduct a hands-on workshop using a CubeSat model developed in this program and competition based on the content learned in the KOSEN Space Academia (see Fig.2.). This camp is largely following the know-how obtained up to 2018, with the aim of providing efficient learning in a short period of time. The KOSEN Space Camp has been held since 2015 and was held for the fifth time (five consecutive years) in 2019.

In 2017, the hands-on workshop and competition of CanSat, which is a mock satellite in the size of a drink can, was almost completed. Based on this, the following two items were newly tackled from 2018.

1) Development of an improved 2U size CubeSat model for hands-on workshop.
2) Conducting a competition with above CubeSat model by hanging down from a rubber balloon.

Fig. 2. Actual scene at the KOSEN Space Camp. (Upper left: the hand-on workshop separating several groups, Upper right: Sample of the CubeSat model developed in this program, Lower left: Competition of the power system using CubeSat model, Lower right: competition with the CubeSat model by hanging down from a rubber balloon).

As stated above, the KOSEN Space Camp has been held since 2015 and continuously implemented until 2021[7]. In this paper, however, we report only for two years from 2018 and 2019, as they are funded by MEXT program which focused on this paper. The number of participants of the KOSEN Space Camp is listed in Table 2. A total of more than 80 students and faculties participated in the program.

Table 2. Number of participants for the KOSEN Space Camp.

FY	KOSENs	Students	Faculties
2018	11	37	15
2019	10	31	13
Total	21	68	18

2.3. Primary achievement of the KOSEN Space Academia and Camp

A total of 263 students and 68 faculty members participated in the program during the three years of the program, of which a total of 195 students from 42 KOSENs (43 campuses) were the participants of the KOSEN Space Academia. As shown in Table 1, the number of participants has increased over the years. In addition, the KOSEN Space Camp, had participants of 37 students and 15 faculty members in 2018 and 31 students and 13 faculty members in 2019. We have conducted questionnaire-based feedback for both the KOSEN Space Academia and Camp, and the percentage of positive responses (3 or more on a 5-point scale) has always exceeded 90. This indicates that we were able to implement programs with a high level of participant satisfaction.

All the teaching materials developed in this program were documented with a list of parts and production methods and could be provided to the persons who requests us. We have also prepared a manual for the implementation of the KOSEN Space Camp and are ready to provide the necessary information when other organizations attempt to implement similar educational program. The teaching materials produced so far have been used in visiting classes and general lectures at each KOSEN, and 21 cases of use have been achieved for three years in the program period.

3. Actual development of CubeSat under the collaboration with 10 KOSENs

The primary purpose of this program is to develop the first CubeSat by the student of national KOSEN, while the education programs mentioned in the section 2 is to cultivate the student's ability to involve such an actual CubeSat development.

Tokuyama KOSEN and Kochi KOSEN individually started the developing satellites for different scientific missions. The CubeSat of Tokuyama KOSEN is focused on the observation of the geomagnetic field in low earth orbit using the small magnetometer (shown in Fig. 3). On the other hand, Kochi KOSEN was developing the CubeSat for observation of the Jovian radio emission (shown in Fig. 4). Among them, the CubeSat of Kochi KOSEN was adopted as the second Innovative Satellite Technology Demonstration Program proposed by JAXA in 2018. As a result, the CubeSat of Kochi KOSEN decided to be a payload of the Epsilon Rocket launched in 2020. In response to this result, the satellite was named as "KOSEN-1" [8] and the developmental regime was concentrated into the KOSEN-1. The system block is shown in Fig. 5. The satellite system consists of several subsystems such as communication system, power system, attitude determination and control system, and so on. In this development, each subsystem was divided among 10 KOSENSs. On the other hand, the CubeSat of Tokuyama KOSEN was set as the second priority and continued to be developed in parallel to be released from the International Space Station (ISS) as the second satellite after the launch of KOSEN-1.

As the main mission of KOSEN-1 is to observe the Jovian Radio emission which wavelength is longer than 10 m, the satellite was required to deploy the antenna with a length of about 7 m as shown in Fig. 4. In addition, some secondary missions are also decided through the Mission Definition Review process. Each mission and success criteria are summarized in the Table 3.

The development of KOSEN-1 continued under the collaboration with 10 KOSENs even after this program ended in 2019. Then finally launched by Epsilon Rocket 5 on 9th November 2021. As of January 2022, the satellite beacons have been received successfully, and the operation is running smoothly.

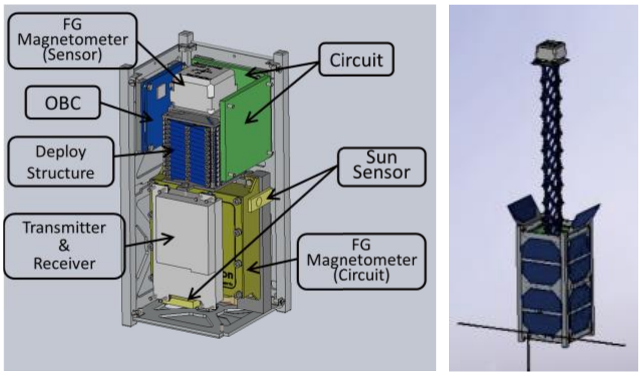

Fig. 3. The schematic illustration of the CubeSat proposed by Tokuyama KOSEN to observe the geomagnetic field in LEO.

Fig. 4. The schematic illustration of KOSEN-1 satellite which is proposed by Kochi KOSEN to observe the Jovian Radio Emission.

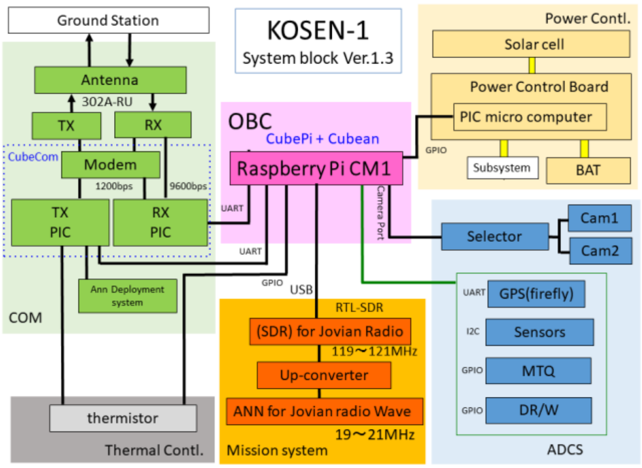

Fig. 5. Diagram of the system block of KOSEN-1 satellite.

Table 3. Success criteria of the KOSEN-1 satellite.

	MS*	Evaluation	Verification
Minimum Success	(a)	Booting of Raspberry Pi CM1	Confirm the OBC boot through downlink data
	(b)	Rotation of D-RW (each side)	Confirm the rotation of D-RW by the external sensor
	(c)	Operation of the latch mechanism for deployment	Confirm the deployment by the camera images
Full Success	(a)	Running the command	Confirm by the downlink data
	(b)	Attitude change by D-RW	Confirm the attitude change during the operation of D-RW by downlink data
	(c)	Deployment of antenna	Confirm the length of the antenna by the camera image
Extra Success	(a)	Long duration operation in orbit	Successful downlink continuously at least one year
	(b)	Feed-back control by image data	Confirm the error of Attitude angle determination accuracy is less than 5 degree by the temporal variation of the attitude data
	(c)	Observation of Jovian radio emission	Confirm the radio received data and time stamp through the downlink data

*: MS represents missions of (a)OBC demonstration, (b)Dual Reaction Wheel, and (c)Antenna Deployment.

4. Primary achievement of 3-years program

Through this three-yeas human resource development programs, several achievements are made in both education and actual satellite development. In this section we summarize the primary achievement which can evaluate this program.

4.1. Subsequent career paths of participating students

This program is designed to educate the students of KOSENs, who have been receiving practical engineering education from the age of 15 with an emphasis on practical experiments. For the essential understanding of satellite development, the students required to understand a representative of complex technology, through collaboration among students from various specialized departments. Through this program, we were able to develop students as human resources who can (1) have a technical background based on the specialty of their department, (2) solve problems other than their own specialty, (3) communicate with students from other KOSENs, and (4) find problems and solve them using capabilities of (1)-(3).

Of the students who participated in this program, 3 students went on to universities and graduate schools in the aerospace field, and 9 students found employment in aerospace companies.

4.2. Additional activities of the students participating this program

Some of the students who participated in this program have voluntarily improved the contents of their courses, leading to extracurricular research and entries in competitions outside KOSEN. For 3 years, a total 13 activities were conducted and 10 of 13 activities were awarded by some contests such as "Satellite Design Contest", "Tanegashima Rocket Contest", "CANSAT Koshien", "Meteorological Instruments Contest" and so on.

4.3. External use of the developed teaching materials

In this program, several teaching materials and methodologies are developed. These teaching materials and educational contents developed in this program are widely used for outreach activities conducted by each KOSEN in addition to Space Academia and Space Camp. From 2017 to 2019, a total 21 outreach activities were conducted by using these teaching materials and/or methodological contents.

4.4. Application for the actual curriculums in KOSEN education

One of the important points to evaluate this program is how the achievement the program spread into more general educations. The essential concepts of the satellite development to be applied for the actual education are (1) combination of many specific subjects, (2) collaboration with many participants to conduct the project, (3) no specific solution to be solved and student required to consider their own problems. The project management procedure to conduct project under the above-mentioned concept are known as Systems Engineering in the field of aerospace engineering. On the other hand, these concepts are considered as an important policy to be applied in more general engineering educations. ABET (Accreditation Board for Engineering and Technology)[9] defined similar concept as "an Engineering Design", which is "*Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions.*"[10] This concept of engineering design has also been addressed by Japan Accreditation Board for Engineering Education (JABEE)[11], by which most of KOSEs are evaluated as an external accreditation.

From above reason, in most of KOSEN, the concept of Engineering Design Education is already involved in their curriculums, so that the systems engineering in the aerospace engineering has high affinity with the education in KOSEN.

From 2017, a part of achievement of this program has been applied to the curriculum in the advanced course of Tokuyama KOSEN. We applied to three classes for "Comprehensive Experiments", "Comprehensive Exercises" and "Comprehensive Exercises for Computer", which are conducted in the first- and second-year students for advanced course (equivalent to the third- and fourth-year undergraduate students in university). The students were assigned a mission for CANSAT (see Fig. 6). As same as space mission, the students need to make a Requirement Allocation Sheet to organize the system requirement and design requirement. This process is following the systems engineering in aerospace field as well as the engineering design defined by ABET.

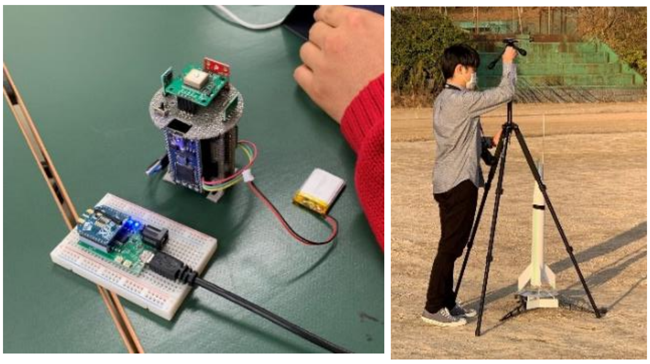

Fig. 6. Actual class conducted in Tokuyama KOSEN. (left: the CANSAT which is produced by the students, right: the preparation of the launch of model rocket for CANSAT)

Table 4 shows an excerpt from the syllabus of "Comprehensive Exercises." The syllabus basically includes the overview of the class, such as objectives of the class, requirement for the students, way of evaluations, and so on. In other words, the syllabus can be considered as the least significant component of the whole curriculum design. These curriculum design methods are almost identical to those used in systems engineering. Reading the syllabus in advance, the students could understand the objectives of the class. The class was designed for the students in advanced course who are equivalent to the fourth year in university, to understand the fundamentals of Systems Engineering and/or Engineering Design and to experience building a CanSat based on the manner of Systems Engineering. For grading the students, three perspectives were defined which are (1) Problem lifting capability, (2) Group development capability, and (3) Result explanation capability. Three achievement levels, which are (1) ideal reach level, (2) standard reach level, and (3) Unreachable level, are described for each perspective.

Table 4. Excerpts from the syllabus of "Comprehensive Exercises".

Objectives			
In order to acquire the ability to design in complex fields, the course aims to provide students with the necessary design methods and development schemes to accomplish their assigned missions, and to gain a consistent understanding of the three systems that make up mechanical and control engineering, from planning to design, based on their basic abilities.			
Rubric			
	Ideal reach level guide	Standard reach level guide	Unreachable level guide
Perspective 1 (Problem lifting capability)	Be able to find the necessary specifications to accomplish the mission and consider engineering issues	Be able to find the necessary specifications to accomplish the mission	Not be able to find the necessary specifications to accomplish the mission
Perspective 2 (Group development capacity)	Be able to proactively lead development discussions	Be able to express own opinions appropriately in discussions about development	Not be able to participate in discussions about development
Perspective 3 (Result explanation capability)	Be able to explain the validity of the developed things and consider issues for improvement	Be able to explain the validity of the developed things	Not be able to explain the validity of the developed things
Class procedures and content and methods			
In this class, we will propose an airborne mission using model rockets and CanSats. Create the implementation methods and specifications necessary to accomplish the decided mission. After that, students will practice the actual model rocket and CanSat development by sharing the roles in groups and perform project management. In this class, students are required to always review and prepare for the course to synthesize the knowledge of individual mechatronics technologies they have already learned. This course requires the following self-study: (1) Conducting a conceptual design and preparation for presentation: 5 hours (2) Fabrication of the model rocket and CanSat: 20 hours (including activities during the summer vacation) (3) Preparation of presentation materials for final presentation: 2 hours (3) Preparation of final report: 3 hours			
How to Evaluate			
(1) Score of conceptual design review (presentation): 10% (2) Score of conceptual design review (report): 20% (3) Score of final presentation: 20% (4) Score of final report: 30% (5) Peer evaluation among students: 20%			

5. Summary

We involved the Human Resource Development program, which was funded by Ministry of Education, Culture, Sports, Science and Technology, from 2017 to 2019 to cultivate the student's abilities to the level where they can develop an actual CubeSat. A total of more than 300 students and faculty members from KOSEN all over Japan participated in this program.

This program created many teaching materials and methodological contents to be applied widely to the more generalized space outreaches. In addition, conceptual procedure was applied to the actual curriculums in the advanced course of Tokuyama KOSEN. It is notable that this program led to develop the KOSEN-1 which was the first CubeSat by national KOSEN. The KOSEN-1 was successfully launched on 9th November 2021, by Epsilon rocket from the Uchinoura Space Center.

Finally, as an inheritance of these achievements, we newly started the second CubeSat development which is named “KOSEN-2” and a new human resource development program funded by the MEXT in which Niihama KOSEN is taking the initiative until 2022.

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