Development of Sustainable Evolutionary Space Human Resource Training Program Using HEPTA-Sat

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ABSTRACT

In recently year, although it is expected that the market of space industry will be higher in the future, there is shortage of human resources in the space field. Such as CubeSat Project, OJT type education, although it can gain knowledges which suit its area, it has some problem which is not to be able to conduct to multiple people, to take a long time and not to get a global understanding about the system. In addition, many tacit knowledges, which are gained through experience so far, may be lost without being inherited to next generation because it was not be formalized. In this paper, in order to solve these problems and develop human resources, we developed an education program. It extracts and inherits tacit knowledge at the same time in a classroom which composed of instructors, students, and teaching materials, and makes it possible to understand nano/microsatellite system engineering. And we clarified its usefulness from the results of the implementation at home and abroad.

INTRODUCTION

Space Industry Development and Human Resource Shortage

The global space industry in recent years has been shifting from the state business to the private business mainly in Europe, and technological innovations in the space industry and the fourth industrial revolution emerge new business which is combined space and IT technology. With the development of the satellite business, attention has been paid to constellations linking dozens of satellites, and the number of micro satellites launched has increased dramatically compared to several years ago. As satellite constellations has been paid attention, the number of micro satellites launched has increased dramatically compared to several years ago. In addition, it is estimated that 2,000 – 2,800 nano/micro-satellites will be launched in five years, and the micro satellite market is also expected to be greatly developed in the future. The world space industry as a whole is expected to become a market of about 70 trillion yen in the 2030s.1 With the development of the space industry like this, it is increasing that the number of new entrants to the space industry and the necessity for the development of the space law and the demand for human resources with specialized knowledge such as space engineering and IT. However, especially in Japanese, space industry has problem that human resources in the space field are short the reason why students who majored in aerospace engineering do not necessarily find employment in the space industry and the reason why there is low influx of human resources from the non-space industry into the space industry. Therefore, in order to support the space industry in the future, it is necessary to develop human resources having knowledge of the space field, that is, to carry out the succession of knowledge and technology widely and to broaden the base of human resources.

Knowledge and Technology Inheritance Problem in Human Resources Development

The kind of know-how that individuals have cultivated from their experiences is called "tacit knowledge", while the verbalized knowledge is called "explicit knowledge". In the field of technology development, not limited to the space field, it is not uncommon for experts with important knowledge and skills to graduate or retire without sufficiently formalizing their tacit knowledge. It is pointed out that the organization's knowledge and technical level declines due to the fact that development know-how and important information are not properly inherited, and they lost. In addition, the reason why an expert can succeed in work is largely due to tacit knowledge acquired from previous experiences, such as "do so in this case". If it is possible to formalize the tacit knowledge of the expert, it is considered to be effective in human resource development. Thus, formalization of tacit knowledge is essential from both the perspective of human resource development and the prevention of loss of tacit knowledge.

Generally, there are two way for knowledge and technology inheritance. One is a method of transmitting knowledge systematized in the past to a large number of peoples, such as university lectures. The other is a method that a small number of people learn the living knowledge in practice from a senior and a boss, such as

on-the-job training (OJT). In technology development, OJT is effective because it is necessary to inherit tacit knowledge such as know-how. As practical space engineering education, the CanSat (simulated artificial satellite of empty can size) and CubeSat (nano/micro-satellites) have been developed. As learning through actual development, although very high training effects can be obtained when there are superiors and seniors, it is limited to upper grades student or graduate student at a university with an aerospace engineering major to obtain such educational opportunity. Thus, there are not so many people to obtain such educational opportunity. In addition, even if they have the opportunity, OJT type education based on such satellite development usually requires a long time of 1, 2 years or more.

It is difficult to take charge of all the systems even if the person in charge takes charge of multiple systems due to the relationship such as the scale of development and the grace period until launch. As a result, it is often impossible to experience the entire system development, and even though you have acquired the ability to perform local optimization at your location, it is not easy for you to understand and learn the global optimization essential to system development.

From the above, it is necessary to provide new education which be able to realize some features listed below.

- To provide many educational opportunities
- To experience the whole system development
- To cultivate the idea of global optimization
- To enable inheritance and formalization of tacit knowledge

However, even if there is such education that makes them possible, it can be easily imagined that the more technology progress, the more obsolete it become only by repeatedly implementing the same content and it makes no sence finally. Therefore, in order to be able to educate the necessary knowledge and technology which suits the era, it is necessary to develop and update the content itself sustainably as the technology advances.

Objectives and Contributions

In this research, with the aim of constructing a space human resource development program that can carry out knowledge and technology inheritance with high distribution, we propose and develop a sustainable evolutionary educational model, material and program. It enables to acquire space systems engineering and micro satellite systems engineering in a short period of time, and to extract, inherit, formalize tacit knowledge. In addition, we show the effectiveness of the educational model, material and program by examining the implementation results of educational programs at domestic and abroad.

EDUCATIONAL MODEL

In this study, we developed the educational program "HEPTA-Sat Training" and the educational material "HEPTA-Sat". The education model proposed in this paper is shown in Figure 1,

1) Participants acquire explicit knowledge through the development of HEPTA-Sat.
2) Tacit knowledge is inherited and extracted in the communication between the participant and the instructor.
3) Tacit knowledge is recorded on the spot, and it is formalized by reflecting it in the teaching material when accumulated to some extent.

It consists of the above three steps. In addition, instructors actually participate in projects such as satellite development, and gain experience in them, and tacit knowledge is accumulated, and it becomes possible to incorporate new technology knowledge and tacit knowledge into educational materials By repeating this flow, it becomes possible to develop new educational materials on a sustainable basis.

Acquisition and Retention of Knowledge in Experiential Learning

HEPTA-Sat Training is hands-on educational program. In self-study by lectures and books at universities etc., it tends to be only to input knowledge by reading and listening to the contents of lectures and books. On the other hand, in HEPTA-Sat Training, participants develop the model satellite "HEPTA-Sat" while reading the textbook that is technical description and instruction manual. Participants read the textbook and inputs the knowledge, and then outputs it through assembly, software integration, functional test etc. In each phase, they can gain feedback from HEPTA-Sat such as the power cannot be turned on, the program cannot be compiled, and the obtained data is incorrect etc. Based on the feedback, they will face the event and consider why it behaves like that and why it does not work properly. Repeating backward reasoning and forward reasoning, they find out causes and reasons and consider them. As a result, when it is solved, it is accumulated as its own lesson.

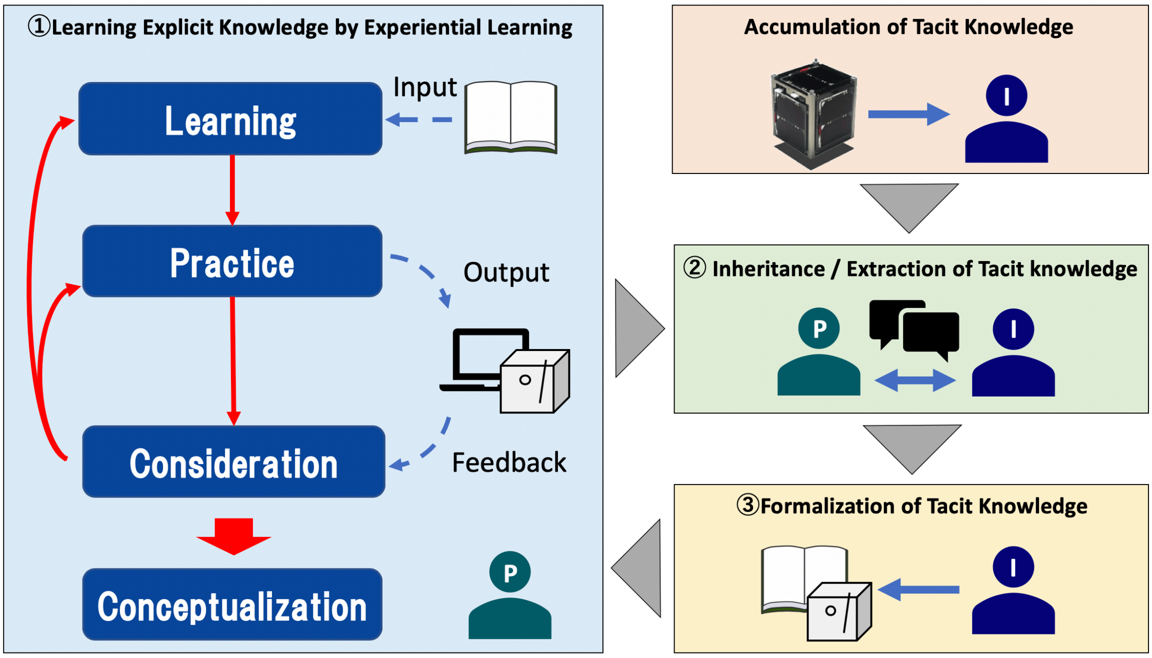

Figure 1: Educational Model of HEPTA-Sat Training

In HEPTA-Sat Training, this series of cycles can be repeated at short intervals, and the difference between each step is designed as small as possible, so it will always repeat to input, output and consider in similar situations during training. This makes it possible to conceptualize the cause, reason, and solution for a certain event, and accumulate it as knowledge that can be applied to other situations. And they can turn it into further learning by practicing it again.

Inheritance, Extraction and Formalization of Tacit Knowledge and Sustainable Development of Educational Material

In order to realize the inheritance, extraction and formalization of tacit knowledge, the HEPTA-Sat Training consists instructors who have satellite development experience, participants and educational materials.

The SECI model is known as a framework of knowledge management focusing on knowledge creation. The SECI model is a model that manages knowledge by performing knowledge conversion by dividing the knowledge conversion mode into four and setting each place. Based on the SECI model, the knowledge transformation in HEPTA-Sat Training is explained (Figure 2).

In the process of developing HEPTA-Sat, participants absorb the systematized explicit knowledge as tacit knowledge of the individual (internalization). After that, in the communication repeated between the instructor and the participants, tacit knowledge is inherited to participants from instructors (socialization). In addition, participants' tacit knowledge is also shared with instructors. And, by recording the contents, tacit knowledge can be formalized (externalization). After the program has been implemented several times, it is reflected on textbook and HEPTA-Sat that the knowledge which has been formalized(combination). As a result, instructor's tacit knowledge is formalized as educational material.

Because the participants' backgrounds are diverse, we can consider that the contents of communication between instructor and participant are different, thus various tacit knowledge can be extracted.

In addition, since instructors can accumulate new tacit knowledge by gaining experience in the project, new tacit knowledge is extracted, inherited, and formalized each time this training program is executed. Thus, it is possible to develop the educational materials on a sustainable basis.

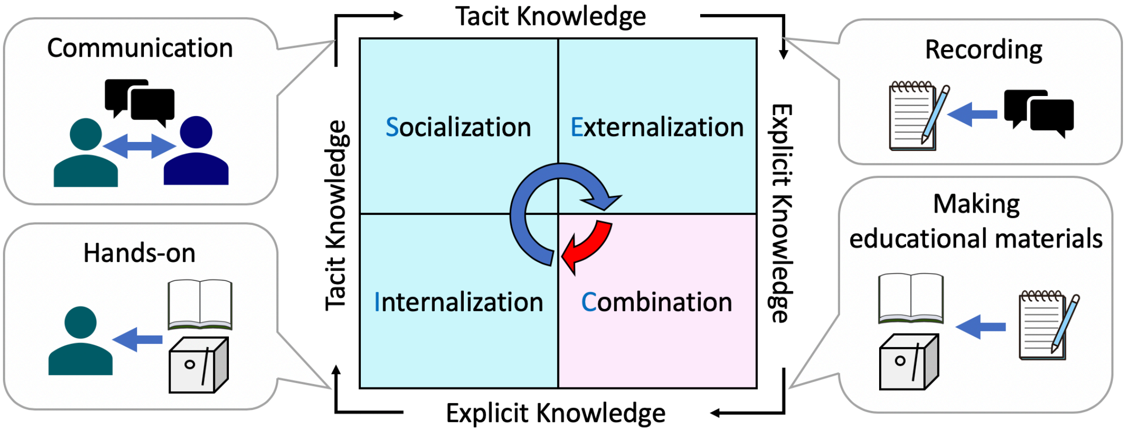

Figure 2: Knowledge Transformation of HEPTA-Sat Training

Evaluation of Comprehension Level

In order to evaluate the effectiveness of the program, participants' understanding and satisfaction are surveyed by questionnaires before and after the program implementation. In addition, the survey of understanding level by questionnaire is self-evaluation, and in order to evaluate objectively, a comprehension check test is performed after the program.

HEPTA-Sat Training and the textbook are organized in units of Lab corresponding to the satellite subsystem. In order to measure the comprehension level in each Lab, we set question to evaluate comprehension level about each Lab on a scale of 1 to 5. In addition, in the comprehension check test, we set up questions about important phrases and ideas for each Lab. We have also set questions to describe the basis of answers in free description, which leads to deepening the degree of understanding by making them recognize what they understand and what they do not understand. In the future, we aim to establish a system that, when you answer the wrong one, identifies why you made a mistake and automatically points out a point to review.

In addition, we are examining whether this educational material or program can be used as an evaluation system of human resources suitable for micro satellite system development and other system development. For that purpose, it is problem that how measure not only comprehension level but also non-cognitive ability such as solving problem ability, management ability, response ability to sudden events like changes of requirements etc. Thus, we need to consider the way of visualization and evaluation such abilities.

Internationally Spreadable Package

As mentioned in the first part, OJT is widely used in the field of human resource development. It is not suitable for widely deploying knowledge and technology since it takes a long time and there are few people who can receive knowledge and technology like one-on-one.

On the other hand, HEPTA-Sat Training is able to conduct training with multiple people anywhere, as long as it has the Internet environment and PC, kit, and instructor due to packing content into one box and making it into a kit. Thus, it is suitable for spreading knowledge and technology.

In order to provide the education to many people, it is necessary not only to make contents spreadable easy but also to increase educational opportunities. We are recruiting collaborators who agree with HEPTA-Sat Training Program as instructors and facilitators promoting activities in Japan and abroad. We are trying to establish activity bases in various places. In addition, a program for fostering instructors is also implemented every year, and a license system is being established to enable those who completed the program to implement the program in their home countries and neighboring countries.

EDUCATIONAL MATERIAL & PROGRAM

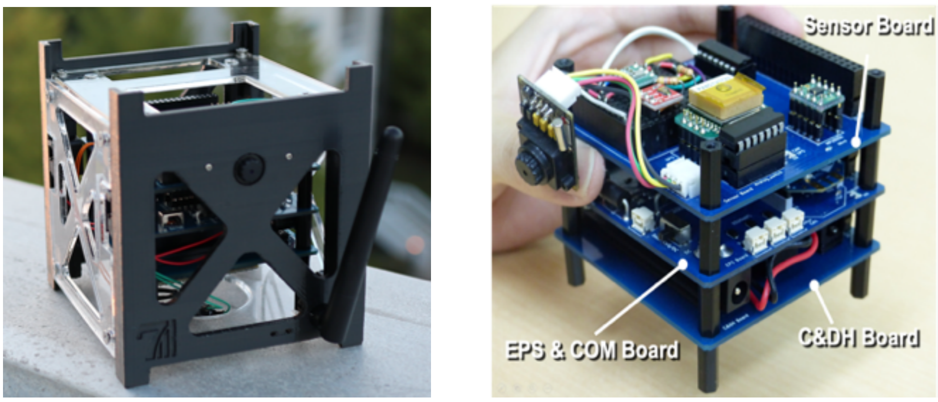

Figure 3: HEPTA-Sat (Right: Inside of Structure)

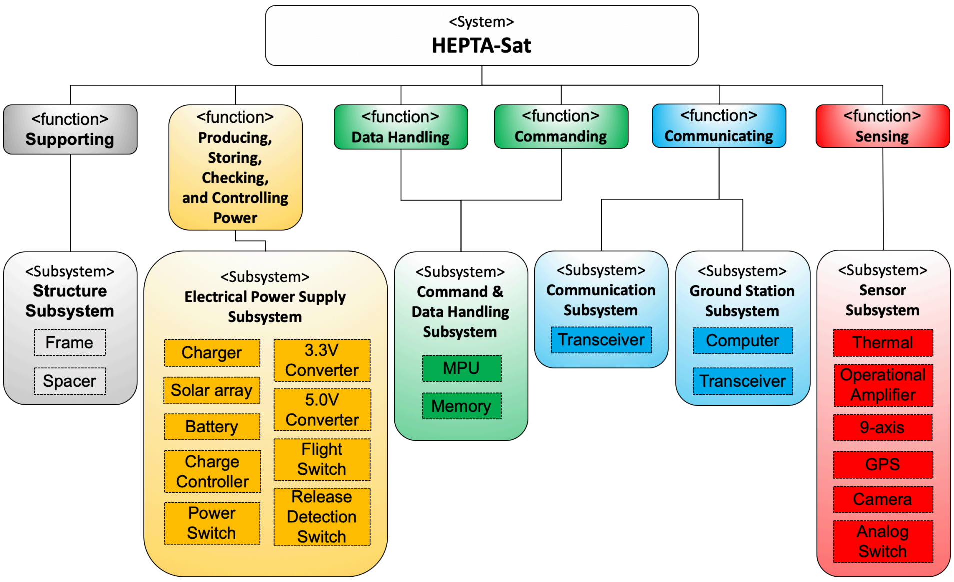

Figure 4: System Architecture of HEPTA-Sat

Model Satellite "HEPTA-Sat"

The nano/micro satellite education kit "HEPTA-Sat" (Figure 3) is the same size as 1U (10 cm cubic) CubeSat which is developed worldwide actively. In addition, it has almost the same function as CubeSat. Thus, participants can learn basic satellite system architecture and functions.

Each component is mounted on three boards, and six subsystems (structure, power supply, command & data processing, communication, sensors) realize six functions (Figure 4).

Participants can simulate communication between the satellite and the ground station by connecting a communication device same as HEPTA-Sat to the PC.

Because most components are DIP type (implemented by plugging in a socket), participants do not require soldering skills, and anyone can easily develop anywhere with the Internet and a PC.

Textbook with Integrated Technical Description and Instruction (Procedure) Manual

As shown in Table 1, the textbook consists "Introduction" to understand the definition and usefulness of nano/micro satellites, and "Lab1 ~ Lab7" to understand programming language, the role of each subsystem that composes the satellite, and the design / assembly / integration method. The contents start with the outline of the nano/micro satellite and continue to the basics of programming and the chapters of each subsystem that composes the satellite.

In each subsystem chapter (Lab X), there are mainly two parts. One is the Lecture Part that explain general satellite functions, technical terms related to them, and HEPTA-Sat system architecture. The other one is Hands-on Part where assembly, integration, and test methods are described step by step like instruction manuals. Each chapter is organized in order of general theory, concrete theory and practice. And each step is structured so as to minimize the difference so as not to jump. Therefore, you can gain the minimum knowledge necessary for nano/microsatellite development even through self-study.

In addition, by periodically revising the kit and the text, we can formalize tacit knowledge extracted in the program.

Table 1: Contents of Textbook

Chapter	Descriptions
Intro.	What is CubeSat? How to develop it?
Lab#0	Components Specification and Selection
Lab#1	Construction of Development Environment for Hands-on Training and Programming Practice
Lab#2	Electric Power Supply (EPS) Subsystem Design and Management
Lab#3	Command & Data Handling (C&DH) Subsystem Design
Lab#4	Sensor Subsystem Design
Lab#5	Communication (COM) Subsystem and Ground Station (GS) Subsystem Design
Lab#6	Structure (STR) Subsystem Design
Lab#7	Mission Design, System Design and Implementation

Curriculum of HEPTA-Sat Training

The nano/micro satellite system education program "HEPTA-Sat Training" is composed of two parts, the basic part and the application part as shown in Figure 5. It consists of a basic part consisting of Intro and Lab0 to Lab6, and an application part consisting of Lab7.

The basic part aims to understand the satellite system architecture through the development of HEPTA-Sat. The application part aims to deepen understanding by practice of the knowledge acquired in the basic part and to acquire the concept of systems engineering while thinking about what is necessary for actually making their satellites successful through the proposal and implementation of the mission.

As described in INTRODUCTION, in the case of OJT type education by micro satellite development project, it takes a long time of 1 to 2 years to experience the whole system development. And it is difficult to look over and understand the whole system because project members are divided into each subsystem. On the other hand, in HEPTA-Sat Training, participants can experience entire system development process not only development of HEPTA-Sat but also mission proposal, mission implementation and mission/result review in a short time of about one week.

At the development stage in basic part, the process of understanding, assembling, integrating and testing functions is repeatedly performed step by step from component level to subsystem level, system level until the system is integrated. In this way, participants can aware of the connection between component / subsystem / system such as how a component constitutes a subsystem or system, or how a component behaves within a system or subsystem. As a result, participants can learn not only local understanding but global understanding.

In the mission design of the Application Part, by thinking about what you actually want to achieve using satellites, it makes easy to come up with many critical questions that you were not aware of just looking at the textbook. By discussing their questions with instructors, participants will gain a deeper understanding and knowledge. In addition, in order to demonstrate the mission, participants need to develop systems in their groups. Through the mission implementation, participants review and perform what has been learned in the Basic Part automatically, which is leading to an increase comprehension level.

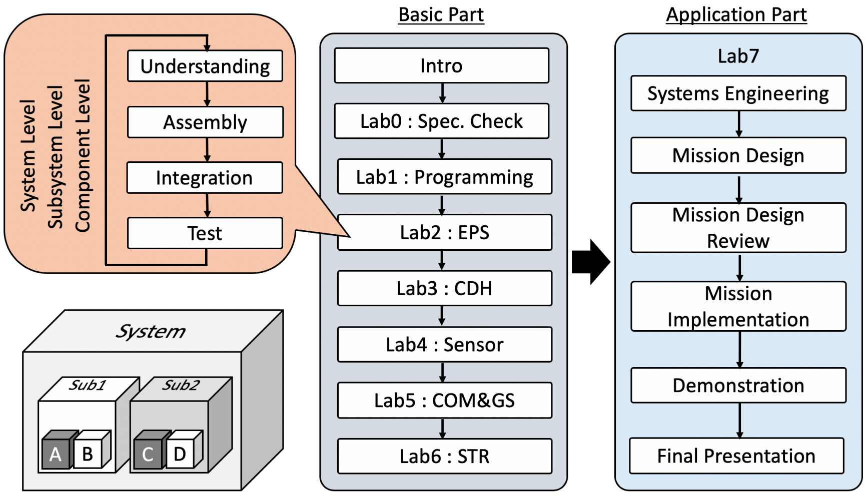

Figure 5: Curriculum of HEPTA-Sat Training

IMPLEMENTATION RESULTS

Past Result of HEPTA-Sat Training

The program was launched in earnest overseas from September 2017, by March 2019, a total of 13 training sessions were given to various organizations and people from industry, academia and government, humanities and sciences all over the world. And 231 people from 38 countries participated in HEPTA-Sat Training.

Figure 6 shows the distribution of participants, and Table 2 shows the number of participants of each country. The green country represents the country where HEPTA-Sat Training was implemented, and the blue country represents the country of origin of the people who participated in HEPTA-Sat Training. In addition, red circles represent ratio of participant in the region to all participants.

Not only Japan but also participants from various parts of the world can offer programs to many people, which demonstrates the height of distribution.

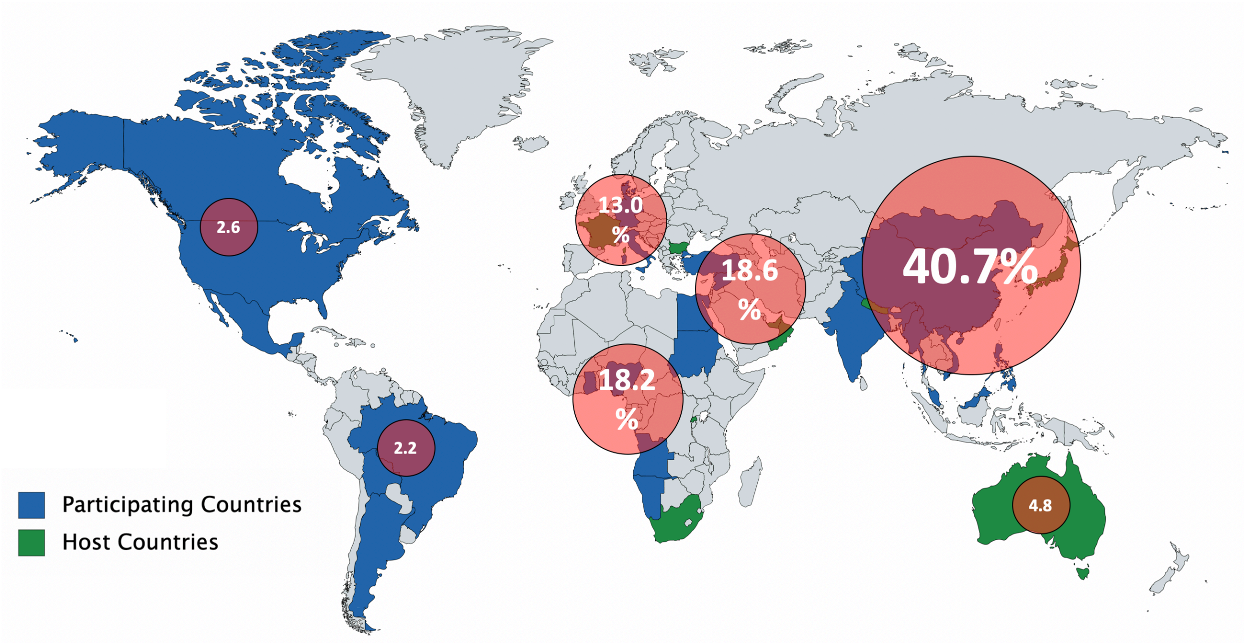

Figure 6 : Distribution of Participants

Table 2 : The Number of Participants

Africa		Europe		West Asia		East Asia		North America		South America		Oceania		ALL
Angola	1	**Bulgaria**	19	**Oman**	19	China	17	Canada	1	Argentina	1	**Australia**	11	-
Egypt	3	Denmark	1	Syria	1	India	5	El Salvador	1	Bolivia	1	-	-	-
Ghana	1	**France**	6	Turkey	1	**Japan**	44	Mexico	3	Brazil	2	-	-	-
Kenya	1	Germany	1	**UAE**	21	Malaysia	3	USA	1	Nigeria	1	-	-	-
Mauritius	1	Italy	1	-	-	Mongolia	2	-	-	-	-	-	-	-
Namibia	1	Luxembourg	1	-	-	Myanmar	2	-	-	-	-	-	-	-
Rwanda	25	Switzerland	1	-	-	**Nepal**	18	-	-	-	-	-	-	-
South Africa	9	-	-	-	-	Philippines	2	-	-	-	-	-	-	-
Sudan	1	-	-	-	-	Vietnam	1	-	-	-	-	-	-	-
TOTAL	43	TOTAL	30	TOTAL	42	TOTAL	94	TOTAL	6	TOTAL	5	TOTAL	11	231
RATIO	18.6%	RATIO	13.0%	RATIO	18.2%	RATIO	40.7%	RATIO	2.6%	RATIO	2.2%	RATIO	4.8%	100%

Result of Questionnaire and Discussion

Figure 7 shows the questionnaire items and the ratio of engineers / non-engineers of the participants, and Figure 8 shows the results of the questionnaires conducted to the participants so far.

As for the items related to the evaluation of the comprehension level of the questionnaire, the same questions were placed in a five-step evaluation before and after the program implementation in order to measure changes before and after each implementation.

From Figure 7 and 8, regardless of the engineer or not, in all the items, the figures after implementation were higher than before the implementation of the program. As a result, participants can deepen their understanding of each subsystem and acquire knowledge about the entire satellite system through the program.

Also, from questionnaire result "I was able to learn the essentials of manufacturing in space in a short period of time" and "I was able to understand the functions of the satellite system", we can say that this program is effective for human resources development in the space field, regardless of developers and users.

Some participants commented that it was good to have a simple lecture before starting hands-on in each Lab. At present, because we put emphasis on hands-on learning and respected their own pace, so the instructor had only explained Intro at the beginning of the program. Therefore, we need to consider how to lecture such as brief explanation is given at the start each Lab.

Q1	Merit & demerit of Nano Satellite
Q2	EPS Subsystem
Q3	CDH Subsystem
Q4	Sensor Subsystem
Q5	COM Subsystem
Q6	GS Subsystem
Q7	STR Subsystem
Q8	Assembly and System Integration

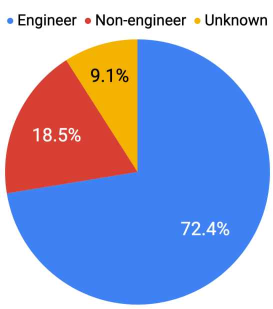

Figure 7 : Contents of Questionnaire / Rate of Participants

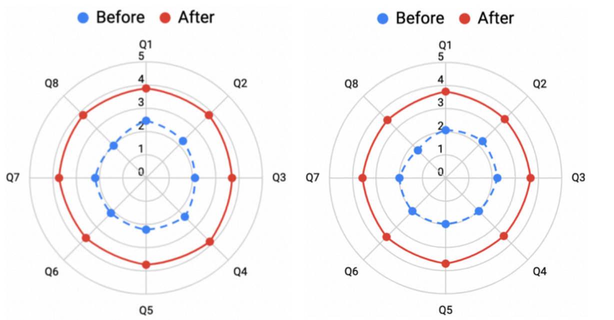

Figure 8 : Results of Questionnaire (Left: All, Right: Non-Engineer)

CONCLUSION

In this study, we aim to develop a space human resource development program with high spread of knowledge and technology transfer. For that purpose, we proposed a sustainable evolutionary educational model, material and program that can acquire micro satellite system engineering in a short period of time and enable extraction, inheritance and formalization of tacit knowledge. In addition, the results of the implementation in Japan and abroad showed that the proposed educational model, material and program are effective regardless of engineer and non-engineer.

Future works

In systems engineering, there is vee model which show system development flow. HEPTA-Sat Training has contents of the right side of vee model (assembly, functional test and verification etc.). But it does not have enough contents of the left side of vee model (requirement analysis or function analysis etc.). Therefore, we need to add contents of upstream design based on systems engineering to develop human resources who can understand and develop space systems.

In addition, evaluation system is just self-evaluation now. We need to consider evaluation method in order to evaluate objectively.

References

1. Ministry of Economy, Trade and Industry, "Report of the study meeting for strengthening human base in space industry field," 2018.
2. Space Policy Committee Space Industry Promotion Subcommittee, "Space industry vison 2030," 2018.
3. Ikujiro Nonaka, "The Knowledge Creating Company," 1996.