The Effects for Programming Learning Using Actual Robots Control with Scratch

Masahiro Osogami and Kazutomi Sugihara
Department of Management and Information Sciences, Fukui University of Technology, Fukui, Japan
Email: osogami@fukui-ut.ac.jp, sugihara@fukui-ut.ac.jp

Kazumasa Ohkuma
Department of Information and Computer Engineering, Okayama University of Science, Okayama, Japan
Email: ohkuma@ice.ous.ac.jp

***Abstract*—Recently, the ICT (Information and Communication Technology) engineers 'workforce shortage has been occurred with the progress of ICT development. In the new educational guidelines of Japan, the learning contents about ICT have been extended. Along with this, effective teaching materials for learning programming are in demand. In this study, we constructed a programming learning environment which can control actual robots using Scratch, which was developed at MIT. Using questionnaire data, we analyzed the effect of the learning environment on the learning experience of students. And by the results, it was found that with this learning environment, it is possible to improve the learning effect of any students, regardless of their original interest in computer operation.**

***Index Terms*— programming education, scratch, LEGO mindstorms, micro robots**

I. Introduction

With the recent remarkable progress of information society, ICT (Information and Communication Technology) has become essential to our lives. However, according to the annual economic and fiscal report issued in July 2013 from the Cabinet Office of Japan, in regards to labor supply and demand there is a chronic shortage of ICT engineers in the workforce [1]. So, the cultivation of ICT engineers has become an urgent task in our country. The workforce shortage of ICT engineers has also become a social problem in other countries.

In the new educational guidelines of Japan, the ICT curriculum in elementary, middle, and high school has been increased [2]. Along with this, a programming module has become compulsory in the Junior High School curriculum. Thus, development of effective teaching materials for learning programming are being researched [3]-[5].

In this paper, we constructed materials for learning programming for beginners. This material can control the actual robots by Scratch script (a program). Scratch is designed to make programs easily by combining blocks like LEGO, with each block having its function written on it. This is very easily understandable especially for programming beginners. Because normal programming languages ask the learner to learn syntax first. However, because of the difficulty of learning syntax, it is often too high a hurdle for programming beginners. On the other hand, Scratch does not need syntax learning as much but instead uses visual algorithms. By using actual robots and Scratch, it is possible to eliminate the steps of program syntax learning, and also to learn algorithms that are more important for programming education. It was our aim to have learners gain an interest in ICT before having to understand complicated coding technology. We analyzed questionnaire data to verify the effects that these learning materials had on the learning experience of students. The results are reported in this paper.

In Section 2, preliminaries are given. In Section 3, analysis of the questionnaire in experimental classes are described. And Section 4 is the conclusion of this paper.

II. Preliminaries

In this section, each element of the learning materials will be descripted. First is the program Scratch, second are the actual robots, and last is the conversion software.

A. Scratch

Scratch was developed by MIT Media Lab at the Massachusetts Institute of Technology[6], and it is open to the public as free software. Scratch was designed to make programs easily by combining blocks with instructions written on them. This eliminates the syntax learning stage of programming acquisition, which is often difficult for programming beginners. Fig. 1 shows a Scratch windows style.

Figure 1. Scratch window style

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Area 1 : Command Group Pallet

Here, we can select the type of blocks which are categorized by their functions.

Area 2 : Block Pallet

There are categorized blocks with instructions written on them.

Area 3 : Scripting Area

Combining blocks dragged from area 2 to here.

The scripting area makes Scratch ‘script’ which equates to a ‘program’ in Scratch.

Area 4 : Action Area

The script which is combined at scripting area controls the behavior of the sprite (in this case the cat).

Area 5 : Sprite / Stage Dock

Sprites and stages using the sprite are defined here.

Using the developed material, we can control an actual robot by controlling the sprite behavior.

Fig. 2, which is an expanded section of Fig. 1, shows an example of script. This script means, “move 10 steps, ten times. Then, turn 90 degrees, and this entire process will be repeated 4 times”. It is easy to understand the meaning and structure of the program, even for programming beginners.

Figure 2. An example of script

B. *Actual Robots*

It is possible to control two types of actual robots from this programming education material. The first are Micro robots, developed by Citizen Watch LTD. and shown in Fig. 3(a), which was used in the MR League of the RoboCup[7]. The other is the LEGO Mindstrom, developed by LEGO and shown in Fig. 3(b), which was used in the ET ROBOCON (ET Robot Contest)[8].

These robots are adopted from robot competitions. This has a good effect on keeping programming beginners motivated for continual learning. Using these materials, these two types of actual robots can be controlled. Other types of actual robots can also be controlled if the control library (or code) was given.

C. *Program Conversion Software*

As written in subsection 2(A), Scratch has merits for programming beginners, but usually it is not possible to control actual Robots, such as those described in subsection 2(B), using Scratch directly. Therefore, we developed a software to convert script made by Scratch to the actual robots’ program language [9]. Fig. 4 is the window of the conversion software. English notations are shown in parentheses under each Japanese line.

This software GUI(Graphical User Interface) was designed by using GTK+. We can control actual robots by the operations from 1 to 5 as follows:

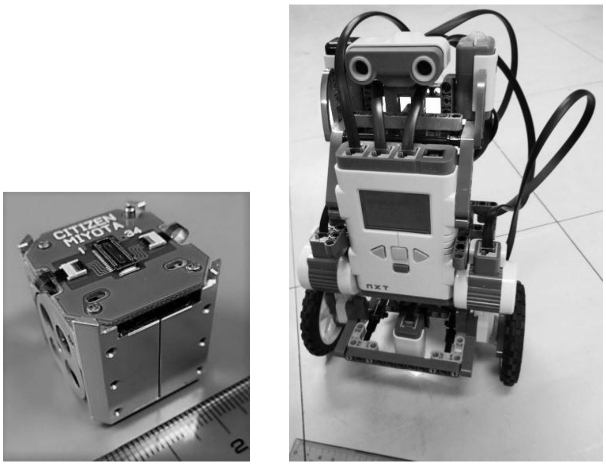
1) Select the robot by the radio button.

2) Select the ID number specified on the communication chip which controls Micro Robot in combo box.

3) Specify the file name which has been written in Scratch script to control the robot.

4) The file name specified at 3 is displayed in the label.

5) Send the signal to control Micro Robot (using only for Micro Robot).



(a) Micro Robot (b) LEGO Mindstorm

Figure 3. Actual robots

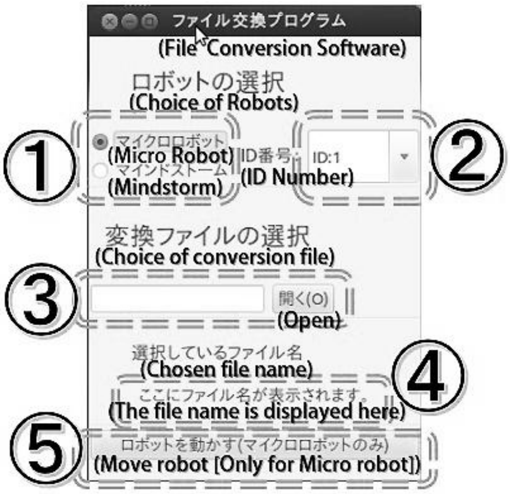


Figure 4. Conversion software window

III. Experience Learning and Questionmarie Analysis

In section contains the analysis of the results from the questionnaire which measured the learning experience of students who used the materials described in Section 2.

A. *Class Design*

Table I shows the class design of the learning experience students had using the materials listed in this study.

TABLE I. THE CLASS DESIGN

Stage (Time)	Learning activities of students	Teacher instruction and assistance
Start the class (5 minutes)	● Answer the questionnaire	● Open Scratch ● Explain questionnaire items
GOAL: program to control sprites (which is the same as actual robot's control) by Scratch		
Introduction (10 minutes)	● Learn the basics of Scratch	● Explain programming methods using Scratch ● Support the participants activate Scratch
	Example: Create a program to move forward	
	● Create a program composed of "move ○ steps" blocks, as shown in Fig. 2	● Explain the method of changing variables in the block and the method of stacking blocks
Build up (15 minutes)	Exercise 1: Create a program to draw a square by moving the sprite	
	● Create a program composed of "move ○ steps" and "turn ○ degrees" blocks, as shown in Fig. 2 ● Simplify the program using "repeat ○" blocks, as shown in Fig. 2	● Have participants create a program that can draw a square by using four step – and turn- blocks ● Introduce how to use a repeat-block
	Exercise 2: Create a program to draw a triangle by moving the sprite	
	● Create a program composed of sequence and iteration process blocks, as shown in Fig. 2	● Have participants learn that the variable of the rotation angle is not an inner angle (60 deg.) but an exterior angle (120 deg.) of an equilateral triangle
	Exercise 3: Create a program to draw a Five-pointed star by moving the sprite	
	● Calculate an angle of five-pointed star Create a program composed of sequence and iteration process blocks, as shown in Fig. 2	● Have participants to find that a variable of the rotation angle is 144 degree to draw a five-pointed star
Development (15 minutes)	● Create a program composed of sequence and iteration process blocks freely. ● Check the actual robots behavior controlled by their program own.	● Convert the Scratch sprite to the actual robot's controlling program ● Send and run the converted program to control the actual robot.
End the class (5 minutes)	● Close Scratch ● Answer the questionnaire	● Allow participants to complete the questionnaire ● Collect the questionnaires

TABLE II. THE BREAKDOWN OF PARTICIPANTS

Total 69 people (43 Males and 26 Females)			
Each school	High school A 28 people	Each grade	1st grade 13 people
	High school B 41 people		2nd grade 51 people
			3rd grade 5 people

B. Configuration of The Students

The learning experience was held for students from two Japanese high schools in Fukui prefecture. The total number of students from the two schools who participated was 70. However, one student's data was excluded due to lack of questionnaire responses. Therefore data from 69 students are analyzed. The breakdown of students are shown in Table II.

C. Results of The Quesionnarire

The results and contents of the questionnaire before and after classes are shown in Table III and IV.

As shown in Table III and IV, questions B through I are the same in both the questionnaire at the beginning of the lesson and at the end. Therefore, the difference in students' ICT consciousness can be shown from the before and after class averages. It should be noted that in this questionnaire, a smaller value indicates a more positive response. Also, the difference of averages in Tables V, and VII through 10, are calculated by subtracting the after class values from the before class values. Therefore, the improved interest in questionnaire items can be shown by a positive difference of averages.

TABLE III. RESULTS AND CONTENTS OF THE QUESTIONNAIRE BEFORE CLASSES

Contents before class	Results			
Before 0) What subjects do you like ?	1 Japanese 16(23%)	2 Mathematics 13(19%)	3 Science 11(16%)	4 Society 11(16%)
	5 English 24(35%)	6 P.E. 25(36%)	7 Technology 8(12%)	8 Art 25(36%)
Before A) I like computer operation.	1 19(28%)	2 17(25%)	3 24(35%)	4 9(13%)
Before B) I acknowledge the importance of absorbing knowledge about computers.	1 30(43%)	2 32(46%)	3 4(6%)	4 3(4%)

Before C) I have the desire to pursue an ICT-related vocation.	1 6(9%)	2 22(32%)	3 24(35%)	4 17(25%)
Before D) I am interested in application software.	1 8(12%)	2 27(39%)	3 21(30%)	4 13(19%)
Before E) I am interested in computer hardware.	1 12(17%)	2 16(23%)	3 28(41%)	4 13(19%)
Before F) I am interested in machine control by Programming.	1 5(7%)	2 24(35%)	3 22(32%)	4 18(26%)
Before G) I prefer practical work to lecture in classes of information sciences.	1 25(36%)	2 28(41%)	3 8(12%)	4 8(12%)
Before H) I acknowledge the importance of computer knowledge in daily life.	1 33(48%)	2 29(42%)	3 4(6%)	4 3(4%)
Before I) I regard computer knowledge to be useful for the future.	1 35(51%)	2 22(32%)	3 11(16%)	4 1(1%)
Before J) I can keep up in information science classes	1 9(13%)	2 32(46%)	3 14(20%)	4 7(10%)

Meaning of choice number (1: strongly agree, 2: agree, 3: disagree, 4: strongly disagree)

TABLE IV. RESULTS AND CONTENTS OF THE QUESTIONNAIRE AFTER CLASSES

Contents after class	Results			
After A) I understood today's lecture.	1 25(36%)	2 40(58%)	3 2(3%)	4 2(3%)
After B) I acknowledge the importance of absorbing knowledge about computers.	1 31(45%)	2 33(48%)	3 3(4%)	4 2(3%)
After C) I have the desire to pursue an ICT-related vocation.	1 8(12%)	2 22(32%)	3 24(35%)	4 15(22%)
After D) I am interested in application software.	1 14(20%)	2 29(42%)	3 18(26%)	4 8(12%)
After E) I am interested in computer hardware.	1 16(23%)	2 23(33%)	3 20(29%)	4 10(14%)
After F) I am interested in machine control by Programming.	1 14(20%)	2 24(35%)	3 19(28%)	4 12(17%)
After G) I prefer practical work to lecture in classes of information sciences.	1 28(40%)	2 30(43%)	3 4(6%)	4 7(10%)
After H) I acknowledge the importance of computer knowledge in daily life.	1 36(52%)	2 26(38%)	3 5(7%)	4 2(3%)
After I) I regard computer knowledge to be useful for the future.	1 31(45%)	2 26(38%)	3 7(10%)	4 4(6%)
After J) I had fun during today's class.	1 42(61%)	2 19(28%)	3 3(4%)	4 4(6%)

Meaning of choice number (1: strongly agree, 2: agree, 3: disagree, 4: strongly disagree)

TABLE V. AVERAGES OF EVALUATION VALUE DIFFERENCES BEFORE AND AFTER CLASSES

Question	B	C	D	E	F	G	H	I
Average of before class	1.7101	2.7536	2.5652	2.6087	2.7681	1.9855	1.6667	1.6812
Average of after class	1.6522	2.6667	2.2899	2.3478	2.4203	1.8551	1.6087	1.7647
Difference of averages	0.0580	0.0870	***0.2754**	***0.2609**	***0.3478**	0.1304	0.0580	-0.0835
p-value	0.4368	0.1093	0.0004	0.0011	0.0000	0.0832	0.4835	0.3880

In Table V, each average value of before and after the classes and the difference of their average values are shown. Table V contains the average value of each item from the before-class and after-class questionnaires, along with the difference in their average values. An F-test confirmed that there was not a significant difference in the distribution. Values which are statistically significant at the 0.05 level, as determined by a T-test, are marked with a '*' in the upper left corner of the values.

Shown in Table V, the difference of averages from before and after classes are all positive values except for question I, which has a negative value of -0.0835. The difference in averages for question D through F are larger than other questions, and the differences' significance can be confirmed by their p-value.

Hence, these results revealed that the interest in "application software (question D)", "computer hardware (question E)" and "machine control by programming (question F)" have been increased by taking this class. On the other hand, only "knowledge of computers will be useful in your future" (question I) decreased, however it was not statistically significant.

Table VI shows the correlation between each question.

Correlation coefficients of more than 0.7 are marked with a '*' in the upper left corner. According to the results shown in Table VI, the values which have a strong correlation are the combination of "questions C and F of before/after classes", "questions E and F of after classes" and "questions H and I of after classes". The questions are shown as follows:

TABLE VI. THE CORRELATION OF BETWEEN EACH QUESTION

	(Before) B	(Before) C	(Before) D	(Before) E	(Before) F	(Before) G	(Before) H	(Before) I
(Before)B								
(Before)C	0.4539							
(Before)D	0.4581	0.5877						
(Before)E	0.3904	0.6295	0.6273					
(Before)F	0.4206	***0.7183**	0.4613	0.6707				
(Before)G	0.4834	0.6754	0.6230	0.6028	0.5974			
(Before)H	0.6705	0.4327	0.3646	0.5152	0.4007	0.4759		
(Before)I	0.5202	0.5286	0.3662	0.4190	0.4974	0.5805	0.5852	
(After)B	0.6537	0.5190	0.4393	0.4147	0.4614	0.5485	0.6703	0.5876
(After)C	0.3692	***0.8880**	0.5322	0.5326	0.6634	0.6283	0.3840	0.4025
(After)D	0.3059	0.5286	***0.7801**	0.5440	0.3887	0.6063	0.3398	0.3074
(After)E	0.3251	0.6011	0.5611	***0.7964**	0.5823	0.6538	0.4728	0.4201
(After)F	0.3499	0.6939	0.4649	0.6411	***0.8325**	0.6344	0.4063	0.4642
(After)G	0.3731	0.5885	0.5558	0.4984	0.4054	***0.7920**	0.5014	0.4547
(After)H	0.5132	0.4700	0.4046	0.4836	0.4382	0.5724	0.6021	0.6247
(After)I	0.4966	0.5522	0.4270	0.5485	0.5660	0.5996	0.6722	0.6504

	(After) B	(After) C	(After) D	(After) E	(After) F	(After) G	(After) H	(After) I
(Before)B								
(Before)C								
(Before)D								
(Before)E								
(Before)F								
(Before)G								
(Before)H								
(Before)I								
(After)B								
(After)C	0.5283							
(After)D	0.4283	0.5802						
(After)E	0.4684	0.6365	0.6860					
(After)F	0.5213	***0.7645**	0.5782	***0.7609**				
(After)G	0.5750	0.6119	0.6492	0.5955	0.5231			
(After)H	0.5174	0.4119	0.3980	0.5372	0.4540	0.6132		
(After)I	0.5934	0.5393	0.4118	0.5545	0.5708	0.5836	***0.7445**	

C : I have the desire to pursue an ICT-related vocation.
F : I am interested in machine control by Programming.
E : I am interested in computer hardware.
H : I acknowledge the importance of computer knowledge in daily life.
I : I regard computer knowledge to be useful for the future.

C-1 The Results Grouped by Operating Computer Preference

As mentioned above, this experimental class with this environment could improve participants' interest in application software, hardware, and machine control by programming.

Next, we examined the effect of the classes we conducted on the groups of participants who expressed interest in computer operations, and those who did not express interest.

Using the question "I like computer operation." (Question Before A) as a grouping method, the results of those who answered "1: (strongly agree)" or "2:(agree) is shown in Table VII. The results of those who answered "3: (disagree)" or "4: (strongly disagree)" is shown in Table 8.

As shown in Table VII, the difference between the average values of questions E and F is statistically significant. It is understood that the interest in "computer hardware" and "machine control by programming" was improved in the group who liked computer operation.

Next, as shown in Table VIII, are the results for the students who don't like computer operation. The difference between the average values of questions D through F is statistically difference, and the difference in the average value in question E was improved by about 0.1 points, from 0.2222 to 0.3030. Compared to the group who likes computer operations in Table VII, the average difference value is larger. On the other hand, the improved difference of average value in question F decreased by about 0.1 points from 0.3889 to 0.3030. This means that the interest in “machine control programming” increased more for the group of students who liked computer operations than those who didn’t like computer operations.

From these results, in the group which originally liked the computer operations, the interest in the "machine control by programming" was improved, and the interest in the "application software" improved in the group which originally did not like the computer operations.

This is probably because for the students who originally did not like computer operations, they deepened their interest in general “application software”. Whereas the group that originally liked computer operations, they have specific interest in aspects of “machine control by programming” such as functions and structures, including software and hardware.

C-2 The Results From Students Who Think Studying About Computers is Important, Grouped by Whether or Not They Like Computer Operations

Next, we analyzed the results from the group of participants who thought studying about computers is important (Those who answered ‘1’ or ‘2’ on question Before/After B). We did the same analysis as in Section C-1.

The results of the group who prefer to operate computers and think studying about computers is important is shown in Table IX. The results from the group who don’t like operating computers, but think studying about computers is important, is shown in Table X.

TABLE VII. AVERAGES OF EVALUATION VALUE DIFFERENCES BEFORE AND AFTER CLASSES IN THE GROUP WHO ANSWERED THAT THEY LIKE COMPUTER OPERATIONS

Question	B	C	D	**E**	**F**	G	H	I
Average of before class	1.4167	2.1944	1.9722	2.0278	2.3889	1.4167	1.3889	1.3889
Average of after class	1.3611	2.1389	1.8056	1.8056	2.0000	1.2778	1.2500	1.4444
Difference of averages	0.0556	0.0556	0.1667	***0.2222**	***0.3889**	0.1389	0.1389	-0.0556
p-value	0.5347	0.3242	0.0831	0.0187	0.0002	0.0576	0.0960	0.5710

TABLE VIII. AVERAGES OF EVALUATION VALUE DIFFERENCES BEFORE AND AFTER CLASSES IN THE GROUP WHO ANSWERED THAT THEY DON’T LIKE COMPUTER OPERATIONS

Question	B	C	**D**	**E**	**F**	G	H	I
Average of before class	2.0303	3.3636	3.2121	3.2424	3.1818	2.6061	1.9697	2.0000
Average of after class	1.9697	3.2424	2.8182	2.9394	2.8788	2.4848	2.0000	2.1250
Difference of averages	0.0606	0.1212	***0.3939**	***0.3030**	***0.3030**	0.1212	-0.0303	-0.1250
p-value	0.6245	0.2108	0.0017	0.0229	0.0056	0.3792	0.8385	0.5213

TABLE IX. AVERAGES OF EVALUATION VALUE DIFFERENCES BEFORE AND AFTER CLASSES IN THE GROUP WHO THINK THAT STUDYING COMPUTERS IS IMPORTANT AND WHO LIKE COMPUTER OPERATIONS

Question	C	D	E	F	G	H	I
Average of before class	2.1714	1.9429	2.0000	2.3714	1.4000	1.3714	1.3429
Average of after class	2.1143	1.8000	1.7714	1.9714	1.2857	1.2286	1.4000
Difference of averages	0.0571	***0.1429**	0.2286	***0.4000**	0.1143	0.1429	-0.0571
p-value	0.4246	0.0097	0.0502	0.0086	0.6024	0.2320	0.4494

TABLE X. AVERAGES OF EVALUATION VALUE DIFFERENCES BEFORE AND AFTER CLASSES IN THE GROUP WHO THINK THAT STUDYING COMPUTERS IS IMPORTANT AND WHO DON’T LIKE COMPUTER OPERATIONS

Question	C	D	E	F	G	H	I
Average of before class	3.2593	3.0741	3.1111	3.0370	2.4444	1.7037	1.8148
Average of after class	3.1852	2.7407	2.8519	2.7407	2.3704	1.8889	1.9615
Difference of averages	0.0741	***0.3333**	0.2593	***0.2963**	0.0741	-0.1852	-0.1467
p-value	0.4246	0.0097	0.0502	0.0086	0.6024	0.2320	0.4494

The difference between the average values in question D and F improved for those who think studying about computers is important, regardless of whether or not they prefer to operate computers or not. Hence, this means that the interest in the "question D and F" ("application software" and "machine control by programming") have improved.

On the other hand, we predicted that this experimental class would increase the belief that knowledge of computers would be useful in everyday life for those students who think knowledge of computers is important but don’t prefer to operate computers. However, in this analysis, the statistical significance could not be confirmed for the difference in the mean value in

"Question H" ("I acknowledge the importance of computer knowledge in daily life.").

IV. Conclusion

With the development of ICT today and a workforce shortage of engineers, there is an urgent need to cultivate ICT engineers in Japan. In the new educational guidelines of Japan, the learning contents of ICT have been expanded and a new compulsory unit of programming has been added to the junior high school curriculum. Thus, effective learning programming materials are required.

The programming learning material proposed, has the feature which can eliminate the step of grammar acquisition of programming language which is one of the difficult hurdles for programming beginners. This allows learners to learn more important algorithm than grammar through visual recognition, in programming learning. And another feature of this material of controlling actual robots by their own program is that programming beginners can maintain interest.

In this paper, the programming learning material that we proposed has been verified in its effects by the analysis of questionnaire results in the experience learning. The results have been confirmed that the interest in "application software" and "computer hardware", and also the recognition "machine control by programming" have been improved for students.

Furthermore, it was confirmed that there was an interest was improved in all students, regardless of their interest in operating computers, as well as for students who prefer to not operate computers. Therefore, with these results, the learning effect can be expected to be improved for a wide range of students through this learning environment.

In the future, we would like to enhance our studies to expand functions of this learning material.

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Masahiro Osogami was born in 1965, and received a B.S. degree in Electrical Engineering from Fukui University in 1988, and in 2012 a Ph.D. in Engineering degree from Fukui University of Technology.

He is currently professor at Fukui University of Technology in Fukui-city JAPAN. From 1988 to 1991, he worked at IBM of Japan. His research interests include educational engineering, automatic program generation and reachability of petri net.

Kazumasa Ohkuma was born in 1973, and received a B.S. degree in Education from Kagawa University in 1996 and a Ph.D. in Science degree from Kobe University in 2001.

He is currently associate professor at Okayama University of Science in Okayama-city JAPAN. His research interests include basic theory of information and particle physics.

Kazutomi Sugihara was born in 1975, and received a Master's degree from Osaka Prefecture University in 2000 and a Ph.D. in Engineering degree from Osaka University in 2003.

He is currently professor at Fukui University of Technology in Fukui-city JAPAN. His research interests include operations research and data mining.