

Attempting STEM Education in Informal Japanese Educational Facilities Through the Theme of "Sand"

Shoko Sakata*

Yoshisuke Kumano

Shizuoka University Graduate School of Science and Technology, Shizuoka, Japan

**Corresponding author: sakata.shoko.16@shizuoka.ac.jp*

Abstract

The Shizuoka Science Museum RU KU RU and the Lifelong Learning Centers in Shizuoka City, Japan, hold many class sessions for elementary school students. At these sessions, scientific **experiential programs are provided to cultivate children's interests and curiosities in nature and science.** The authors focused on one of the experiential programs and explored ways to make STEM education programs based on the expected science-education programs of the future. The possibility of making and practicing STEM programs was found by consciously incorporating science, technology, engineering, and mathematical activities on the theme of "sand," a material that is familiar to children, into the educational programs.

Keywords: Informal science education, Earth Science, STEM education, Lifelong Learning Center, Science Museum, four Cs

In autumn 2016, the authors visited regions of advanced STEM education in the United States in the states of Washington, Minnesota, and Iowa. This was an opportunity to talk to individuals who are engaged in STEM education and to observe the current situation in the schools, in the **each state's** Department of Education, and in the institutions working on STEM education. In those states, science education has been transitioning into STEM education. The teaching materials for earth science, for instance, have already been provided to children within the STEM learning framework in the U.S. (Kumano, 2017, Sakata and Okumura, 2017). The research and practice of STEM education for various kinds of geological themes are expected to become popular in Japan.

The Lifelong Learning Centers and the Shizuoka Science Museum in Shizuoka City, Japan hold many class sessions for elementary and junior high school students. As an experiential science- education program, these sessions include a course that cultivates children's interests and curiosities in nature and science. The authors had provided experiential science education programs several times at those facilities in the past. Last year (2017), there was an opportunity to practice the educational program at the Lifelong Learning Center and the Science Museum. STEM education and STEM learning has recently been given more attention in Japan. Therefore, in light of new science education initiative results, we were challenged in converting science education into STEM education ("STEMify") for informal educational facilities.

Ryu and Watanabe (2014), Sakai (2012), Kakisaki (2012), and Fukuda and Kanda (2009), indicate the benefits of sand as a teaching material and propose sand-based lessons that provide developmental learning at elementary and junior high schools. Sand, which is familiar to children, is shown to be effective as a regional teaching material and also as a material for environmental education. That seems to be effective in STEM learning as well when students ask questions and define a problem (the theme of learning) as their own.

About STEM Education Innovation

In the United States, the National Science Teachers Association (NSTA) issued position papers that discussed children of the future, their nature, and their ability to

develop 21st century skills (NSTA, 2011). The Next Generation Science Standards (NGSS) were established in order to develop a specific nature and ability in children by utilizing science education (NGSS Lead States, 2013). Work by Bybee (2013, 2014) and other researchers led to these practices. The NGSS shifted from scientific inquiry and introduced **the Three Dimensions of Learning: "Practice," "Crosscutting Concepts," and "Disciplinary Core Ideas."** These are expected to be deeply relatable to the implementation of STEM education (Yager & Brunkhorst, 2014). The NGSS also elevated engineering design to the same level as scientific inquiry. Additionally, the signing of the STEM Education Act into law in 2015 (U.S.A) accelerated STEM education extensively:

The Next Generation Science Standards (NGSS) represent a commitment to integrate engineering design into the structure of science education by raising engineering design to the same level as scientific inquiry when teaching science disciplines at all levels, from kindergarten to grade 12. There are both practical and inspirational reasons for including engineering design as an essential element of science education. (APPENDIX I para. 1 – Engineering Design in the NGSS)

Especially in science education, educational practices which allow children to acquire 21st century skills through STEM education have been conducted. Opposing views state that the lower grade levels of elementary school should focus on the four Cs (Creativity, Critical thinking, Communication, and Collaboration), since 21st century skills cover a lot of ground (Roekel, 2015, Lindeman & Anderson, 2015).

The purpose of this study is to discuss STEM education programs mainly for the grade levels in **the elementary school. Therefore, this study focuses on the children's** creativity, critical thinking, communication, and collaboration as 21st century skills, and discusses the positive results from STEMify trials.

According to results of the field studies conducted by the authors in the U.S., children's achievements improved thirty percent at the STEM Academy in Washington State. At St. Theresa Catholic School in Iowa, the students presented better understandings of study content and concepts, and the girls were more likely to participate than the boys.

In Japan, a new course of study focuses on three ideas: "what students acquire," "how they learn," and "what they learn." In order to accomplish integration of these ideas in the area of science education for young children, the same application of STEM education in the United States is expected to be implemented in Japan.

Methods

Purpose of the Research

In this study, three points were considered in order to try developing the STEM program in Japan: **"incorporate processes of engineering," "incorporate mathematical activities and use of technology," and "conductively engage in** communication and collaboration activities." **Therefore, in addition to incorporating the multi-layered activities of** each STEM category, we decided to investigate the following questions:

- **By conducting "design of research method: using the scientific method" activities incorporated with aspects of engineering, how will children's activities progress?**
- Will we be able to incorporate several activities using technology and mathematical activities into the program?
- Throughout the program, will the children actively participate in communication and collaboration?

Through the examination of three STEM trials, it is possible to clarify the problems **when we try "stemifying" the program into Japanese context. We aimed to develop and establish a STEM education program.**

Program Framework

Practice at the Lifelong Learning Center.

The framework of the Lifelong Learning Center project is as follows. (In addition, the contents were implemented in order from ①.) S, T, E, and M in Tables 1 and 2 represent Science, Technology, Engineering, and Mathematics, respectively.

Place: Shizuoka City Eastern Lifelong Learning Center
 Course name: Toubu kids project
 Date and time: Saturday, June 17, 2017 10:00-11:30
 Target: Twenty elementary school students (grades 1 to 6)
 Contents: Table 1

Table 1
Lifelong Learning Center program contents (Jun. 17)

Activities		S T E M
①	What is sand made from?	S T
②	Let's investigate the sand (How can I find out?)	S
③	Let's find where the sand came from. i) Let's think about how to find (design of research method) ii) Using observation tools such as loupes (magnifier), stereomicroscopes iii) Compare the size and shape of the grain. Compare by what is more or what is less	S E S T S M
④	Present the results based on the data or evidence	S
⑤	Let's draw a picture with your favorite sand	E (Art)

Practice at Shizuoka Science Museum.

Two practices were conducted on September 23 and December 10. The first framework of implementation at the Science Museum is as follows. (In addition, the contents were carried out in order from ①.) The second framework of implementation is the same as the practice implemented at the Lifelong Learning Center. However, the survey chart "sand composition study sheet" was used in the activity of ③ ii).

Place: Shizuoka Science Museum
 Course title: Love science and mathematics class at Fujinokuni Science School
 Date and time: Saturday, September 23, 2017, 10:15-12:00
 Target: Ten elementary school students (grades 4 to 6), nine junior high school students (grades 7 to 9)
 Contents: Table 2

Place: Shizuoka Science Museum
 Course title: Shizuoka Science Adventure
 Date and time: Saturday, December 10, 2017, 10:15-12:00
 Target: Fifty elementary school students (grades 3 to 6)
 Contents: Table 1

Table 2
Science Museum Program contents (Sep.23)

Activities		S T E M
①	What is sand made from?	S T
②	Let's investigate the sand (How can I find out?)	S
③	Let's find where the sand came from. i) Let's think about how to find (design of research method) ii) Using observation tools such as loupe(magnifier), stereomicroscope, survey chart, "sand composition study sheet" iii) Compare the size and shape of the grain. Compare by what is more or what is less	S E S T S M
④	Present the results based on the data or evidence	S

About the Data

Children's worksheets.

The data were collected from the worksheets that children filled out and from the interviews of several people after the end of the sessions. Two things were focused on: whether children understand what sand is (upper column) and whether children can design the research method of their investigation (lower column). In the case when children could not write by themselves (because of their age), their parents helped them to fill out the worksheets.



Figure 1. The questions were prepared on the worksheet whether children understand about sand or they could use the engineering processes.

Surveys.

The surveys were conducted before and after the activity at the third implementation (Shizuoka Science Museum, Dec. 10) in order to clarify how the children changed their self-evaluation throughout the activity. Table 3 shows the survey contents. The questions include the four Cs (Creativity, Critical thinking, Communication, and Collaboration), which were considered important from the point of view of assessment and teaching of 21st century skills by some researchers participating from the National Education Association (NEA) and National Association for the Education of Young Children (NAEYC); this was used as a standard of activity design (Lindeman & Anderson, 2015). Also, intrinsic motivation (Ryan and Deci, 2000) was added into the questions, as it was expected that the children would be motivated by this activity for the STEM education program and would work on the activity with high levels of interest.

Table 3
Contents of the Surveys

	Before the activity (About school program and study)	After the activity (About today's activity)
Intrinsic Motivation	Do you always work with high levels of interest?	Were you able to work on today's activity with high levels of interest?
Creativity	Do you always have many different ideas?	Did you come up with a better idea in today's activity?
Critical Thinking	Do you think of better ideas or solutions, and test them?	Do you think of better ideas and test them out?
Communication	Are you always able to tell your opinion, or to listen to others?	Were you able to express your opinion, or listen to other's?
Collaboration	Are you always able to cooperate with your friends and work on an activity?	Were you able cooperate with your friends and work on the activity?

1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree

Results

Practice at the Lifelong Learning Center.

There were many participants from lower grade levels. Most children were accompanied by their parents (Table 4).

Table 4
Participants' Grade (Practice at Lifelong Learning Center)

Grade	1	2	3	4	5	6	Total
Number	5	7	4	1	0	1	18
%	(28)	(38)	(22)	(6)	(0)	(6)	(100)

Practice at the Shizuoka Science Museum

Fujinokuni Science School.

Participants ranged from **4th** graders in elementary school to **1st** graders in middle school (known as **7th** graders in the U.S.). In this group, there were many older children **than those in the group at the Lifelong Learning Center's session (Table 5).**

As with the practice at the Lifelong Learning Center, the children observed the sand at first and deepened their understanding of sand in general. After that, they attempted to solve the following problem: find the home beach - that is, the sampling site - of the sand from among the candidate sites. The children were put into groups of two and directed to engage in inquiry activities. They considered a research method and decided on a plan. **They observed in detail the six samples and used a "sand composition study sheet."** Based on the results of their survey, they worked on identifying the coast of the sand's home beach through discussion within their two-person group. Additionally, they were able to share the results with other groups.

All the worksheets were submitted. Nine children filled out the column of **"understanding sand,"** and ten children filled out the column of **"design of research method."** There were four children who described the method, eight children who described the

survey items, and three children who described the procedure. Four children answered in multiple columns.

The children successfully used loupes and stereomicroscopes as investigation tools. **In addition, the “sand composition study sheet” was also used as a tool for eight children.** They compared five types of sand by observing the types of minerals constituting the sand, the size and shape of the grains, and the quantity of each constituent. Their investigations led to their own findings.

Since they were engaged in activities by pairs, communication and collaboration within a pair could be carried out very actively, through mutual communication of opinions and cooperation with each other. Even in the final results presentation, they were able to cooperate and share the results, and also were able to listen to the presentations of other pairs.

Table 5

Participants’ Grade (practice at Science Museum: Fujinokuni Science School)

Grade	4	5	6	7	8	9	Total
Number	1	4	2	3	0	0	10
%	(10)	(40)	(20)	(30)	(0)	(0)	(100)

Shizuoka Science Adventure (Dec. 10, 2017).

The participants in the Shizuoka Science Adventure were from grades **3 to 6** in elementary school (Table **6**).

Similar to the previous two practices, the children observed sand and attempted to solve the problem of finding the home beach of the sand or the sampling location where it was collected. In this program, the children made a sand painting using their favorite sands at the end of the program (Table **1**).

There were **thirty-four children who filled out the column “understanding sand,”** and **thirty-five children who filled out the column “design of research method.”** There were twenty-eight children who described the method, nineteen children who described the survey items, and six children who described the procedure. Sixteen children answered in multiple columns.

Because there were a lot of participants in this practice, the activity was carried out in nine groups. Each group had three to four people. The participants knew each other from attending previous science programs curated by Shizuoka Science Adventure. Therefore, they were able to effectively communicate and collaborate through cooperation with each other. Investigating, summarizing and sharing their results were also observed.

Table 6

Participants’ Grade (practice at Science Museum: Shizuoka Science Adventure)

Grade	3	4	5	6	Total
Number	8	9	15	3	35
%	(23)	(26)	(43)	(8)	(100)

Discussion

Results from the Worksheets

In this study, the "design of the research method; using scientific method" was intentionally adopted in the program practice, and the children were given the time to record their thoughts about their inquiry. At first, the children were confused about drawing up ideas for their investigation; however, most of them were able to describe the survey items on the worksheets without guidance from the instructor. The activities, which were ii) using observation tools, such as the magnifier of a stereomicroscope, etc., and iii) comparison, such as observing and comparing the size and shape of the grains of the various samples of sand, were carried out after the recording time. Therefore, the "design of the research method" was effective. Older children participated in the practice at the Science Museum, as compared to the participants at the Lifelong Learning Center. The expression rate of method, survey items, and multiple descriptions in the participants at the Science Museum was lower; however, the expression rate of procedure was higher (Table 7). Thus, it could be said that this group was more likely to conduct more specific exploration activities. Further investigation and consideration of any relation between the age of the child and the use of the "sand composition study sheet" are necessary in the future.

At the Science Museum, when the children were determining the home beach of the sample sand, they referred to the results they generated from iii) comparing the size and shape of the grains and the number of each type of grain with each sand sample. However, the children participating at the Lifelong Learning Center only mentioned the size and shape of the grains, not the amount of each grain. Therefore, in the practice at the Science Museum, "sand composition study sheet" was adopted as a survey tool; whether children paid attention or not to each quantity of the composition was verified. Since there were four children who described the amount of what is more or is less the constituents of sand, the survey chart "sand composition study sheet" was considered as slightly effective. The survey chart was introduced to incorporate mathematical activities-paying attention to numbers, shapes and quantities-into the problems. The use of technology, such as magnifying glasses and binocular stereoscopes, in the activities and the use of "sand composition study sheet" made it possible to incorporate mathematical activities in a complex way. However, not all of the participants paid attention. The chart should be improved.

Table 7

Expression rate of the investigation method

	Written	Method	Survey Item	Procedure	Multiple description
Lifelong Learning Center	15 (100)	7 (46)	13 (86)	2 (13)	7 (46)
Shizuoka Science Museum	45 (100)	32 (71)	27 (60)	9 (20)	20 (44)

Upper row: the number of people;

Written: Had been described

Survey Item: Written about the survey Items

Procedure: The order of investigation is written

Multiple description: Method, Survey item and procedure are all described

Lower row: the expression rate

Method: Written about the method

Survey Results

The children were asked to write a reflection that compared the activity they participated in to their lives in school. Intrinsic motivation and creativity scores increased from pre-activity to post-activity. This result showed that the children had more positive desires to participate in the activity, and that led to an increase in their creativity. It can be said that this program was interesting and enjoyable for the children. In addition, collaboration scores increased slightly. The possible reason for this result is because the children were not informed to decide on their individual roles before they started the activity, even though they were told to cooperate with each other. From now on, intentional direction to assign roles will be needed.

On the **other hand, the children’s scores slightly declined in critical thinking and communication.** Thinking and trying attempts that were thought to lead to critical thinking will depend on the content of the program and the schedule. Thus, this column needs to be studied in the future. The reason why the communication score declined might be because **of questions about “talking” and “listening.”** According to their worksheets, presentations, and work, they communicated with each other very well.

Table 8
Results of survey

	Intrinsic Motivation	Creativity	Critical thinking	Communication	Collaboration
pre	3.859459	3.700000	3.889189	3.764865	3.854054
post	4.131429	3.862857	3.802857	3.714286	3.925714

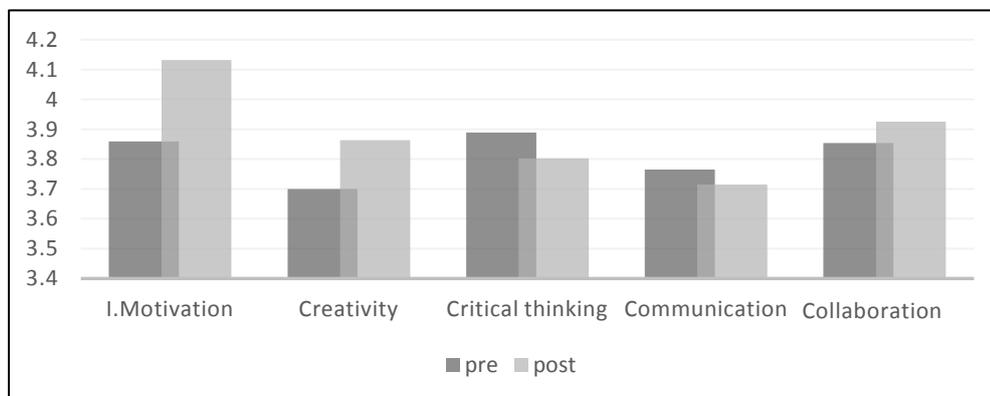


Figure 2. Compared to before the activity, Intrinsic Motivation, Creativity and Collaboration increased.

Conclusion

Three STEM class sessions for elementary to junior high school students at Lifelong Learning Center and Shizuoka Science Museum were the subjects of this study. In addition to incorporating the multilayered activities of each STEM category into the program, the **importance of incorporating “design of research method” into the program was evident** when the STEM programs were designed, because these incorporations made it possible to shift to the next activity and induced the activity. Additionally, subsequent investigations and exploration activities were enthusiastically carried out. The use of technology as defined in the NGSS, in this study, means instruments such as magnifying glasses and stereoscopes,

and the use of "sand composition study sheet" in the activities. These technologies made it possible to incorporate mathematical activities in a complex way. Because two programs were conducted in pairs, communication within the participants' teams was easily facilitated during through the activities. Collaboration was also encouraged. In addition, it was found that communication and collaboration beyond the teams can be expected by including activities that introduce their own conclusions to the other participants and activities that involve creating pictures. The instructors at the beginning of the activity gave the participants the following question in all three practices: ③ "Let's find where the sand came from." Not only should the program include investigations of the characteristics of the sand, but it **should also include engaging stories designed to trigger the children's curiosities** when the goal is to convert the program to STEM. In other words, an engaging story when presenting the assignment should be provided to maintain the intrinsic motivation of the children.

In order to implement the STEM education program, the following should be considered:

- Add "design of research method: using the scientific method" into an activity;
- Add structure that focuses on a number, quantity, and length such as the "Sand composition" study sheet;
- Set up scenarios for the children to express and announce their opinions and results beyond pairs or teams;
- Design a story (necessity) for the activity that makes the children want to work.

We would like to work toward the development of the STEM program while implementing these items in future practices and would also work on a practical study for STEM education in Japanese contexts at the informal educational facilities such as science museums.

Children were able to learn science and science processes in these educational programs. However, it could not be said clearly that children learned engineering processes through these programs. Children seemed to pursue scientific inquiry using technology rather than engineering processes. More consciously, it might have been necessary to incorporate activities that are more concerned with engineering.

In addition, we did not examine whether the programs were three dimensional learning in this study. Because the three dimensions learning is required by NGSS as STEM education, we would like to discuss it in a future study. Additionally, we would like to study about whether the lower grade levels of elementary students are able to learn concepts of science in a crosscutting way through the scientific activities in their integrated-learning class, called "Seikatsu-ka" for 1st and 2nd grade in Japan. We would also like to determine whether the students are able to learn a big concept that will become a core idea in all sections. These examinations are expected to establish a Japanese-style STEM education system in Japan.



Shoko Sakata is a Ph.D. candidate student of Shizuoka University and studies STEM education for K-6 students. She is mainly conducting practical research at informal educational facilities. Ms. Sakata is an Educator at the Shizuoka Science Museum and a part-time lecturer at Tokoha University faculty of education in Shizuoka, Japan.



Yoshisuke Kumano is a Professor of science education at Shizuoka University where he teaches Curriculum Studies, Science Education Methods, Seminar in Science Education and related courses. Now, **Dr. Kumano's** research is mainly focusing on STEM education reforms for Japan, with Ph.D. candidates and other students in his studies.

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