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Development of an Instructional Gaming Material and Design Framework for "Exploration Activities" in Science*

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In Japanese upper secondary schools, students are required to perform "exploration activities." Through these activities, they are expected to increase their interest in science and develop a positive attitude toward utilizing learning outcomes in daily life. However, it is unlikely that science exploration activities will play this expected role in the current context of education. Therefore, the purpose of this study is to propose a design framework comprising lessons and instructional gaming materials for science exploration activities. In this design framework, we intend to integrate technology and science education, and help students learn to solve problems in daily life through technological and scientific ways of viewing and thinking. To this end, we chose the topic of how to create an adequate plastic bottle word sculpture for a campus festival. Students were prompted to consider methods of recycling plastic bottles and to choose an appropriate glue component and mechanism of construction in order to emphasize connections with learning outcomes of technology education and chemistry education. Through the results of a trial lesson with the gaming material, we confirmed the educational effectiveness of the game.

Keywords: science education, upper secondary education, problem-solving, e-learning, simulation and gaming, scientific ways of viewing and thinking, checklist for designing gaming materials

Introduction

In Japanese upper secondary schools, students are required to learn at least one subject from among "Basic Physics," "Basic Chemistry," "Basic Biology," and "Basic Earth Science" in science education (Ministry of Education, Culture, Science, Sports and Technology [MEXT], 2009). In these subjects, "exploration activities" are required for each content unit, such as "energy and motion of the object." In the exploration activities, students are expected to understand domain-specific knowledge better and to cultivate their scientific ability to explore phenomena.

The Central Council for Education (2008) described the following reasons that exploration activities are required. Firstly, according to a survey by the National Institute of Educational Policy Research [NIEPR] (2007), most Japanese upper secondary school students believe that science is useless in daily life, and they do not want to work in jobs that require learning outcomes of science education. Secondly, MEXT's National Course of Studies has focused on cultivating students' abilities of self-learning and problem-solving (MEXT, 1998; 1999), but student achievement in these areas remains insufficient. In order to improve this situation, the

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current National Course of Studies adopts the following three instructional steps for every subject area: “Step 1: Understand fundamental knowledge and train basic skills well;” “Step 2: Utilize acquired knowledge and skills in problem-solving;” and “Step 3: Perform exploration activities.”

However, it is doubtful that exploration activities in science will play the expected role in the new curriculum for the following reasons. Firstly, such activities were already introduced in the previous curriculum (MEXT, 1999), but they did not achieve their objective, as mentioned above. Secondly, the government-authorized textbooks do not provide appropriate examples; instead, they present examples of laboratory experiments for students to collect and analyze quantitative data only by following the textbook’s instructions and answering questions. Thirdly, in Japanese school culture, teachers tend to emphasize preparation for college entrance examinations. They tend to instill domain-specific knowledge and give problems that have a specific correct answer. Fourthly, Matsuda (2012a) found that few student teachers in a teacher training course for certification to teach secondary school science could create appropriate lesson plans for exploration activities. Problems in the plans they created included inappropriate choices of problems, topics not related to daily life, problems with only a single correct answer, and a teacher-centered instruction style.

The point of exploration activities is not to teach new scientific knowledge, but to instruct students on how to solve problems scientifically using the learning outcomes of science education. In this process, they may acquire new scientific knowledge but should not memorize it, because they will be able to acquire it again whenever necessary. We consider that students need to learn methodologies of scientific problem-solving that include identifying problems in daily life and understanding and trying to solve them scientifically; moreover, they should gather data, not by conducting laboratory experiments, but by reading reliable sources on others’ work, such as on the Web or in books. We also consider that appropriate problems for exploration activities should not have a single correct answer, because students need to explore cases in which there are two or more possibilities or even opposing hypotheses. Furthermore, in order to be able to perform exploration activities, it is important for students to find viewpoints for improving their own method of scientific problem-solving when looking back on their own activity results, instead of practicing work according to instructions. We feel that these characteristics are suitable for application to gaming techniques as a method for designing and facilitating learning activities. Here, according to Matsuda (2012b), a game assigns a certain role and goal to each player, and in order to achieve the goal, players choose given alternatives under rules that govern changing situations. In contrast, “gaming” is understood as a style of communication performed in a formal manner, including both briefing and debriefing, before and after game play in the field of Simulation and Gaming. Therefore, the pedagogy of gaming for education is “learning through communication (reflection) about game play,” while the pedagogy of educational games is “learning by doing (playing)” (p. 17).

To realize the policy for exploration activities described above, Ito and Matsuda’s (2013) gaming material for problem-based learning (PBL) in mathematics, and Katto and Matsuda’s (2013) gaming material for science and technology communication serve as useful references. These gaming materials were developed with reference to the design framework of gaming instructional materials for information studies (Hirabayashi & Matsuda, 2011), a compulsory subject area for informatics education in Japanese upper secondary schools. Matsuda (2014) improved the design framework as shown in Figure 1, based on the materials, which were created for many domains. He also stated that problem-solving in daily life should be performed on the basis of his framework, because most problems in daily life are solved by analyzing data collected neither by experiments in a laboratory nor through surveys conducted by the problem solver, but rather data collected from the Web, books, and so on. On the other hand, he also stated that the framework should be extended by adding tasks and ways of viewing and thinking dependent on each subject area.

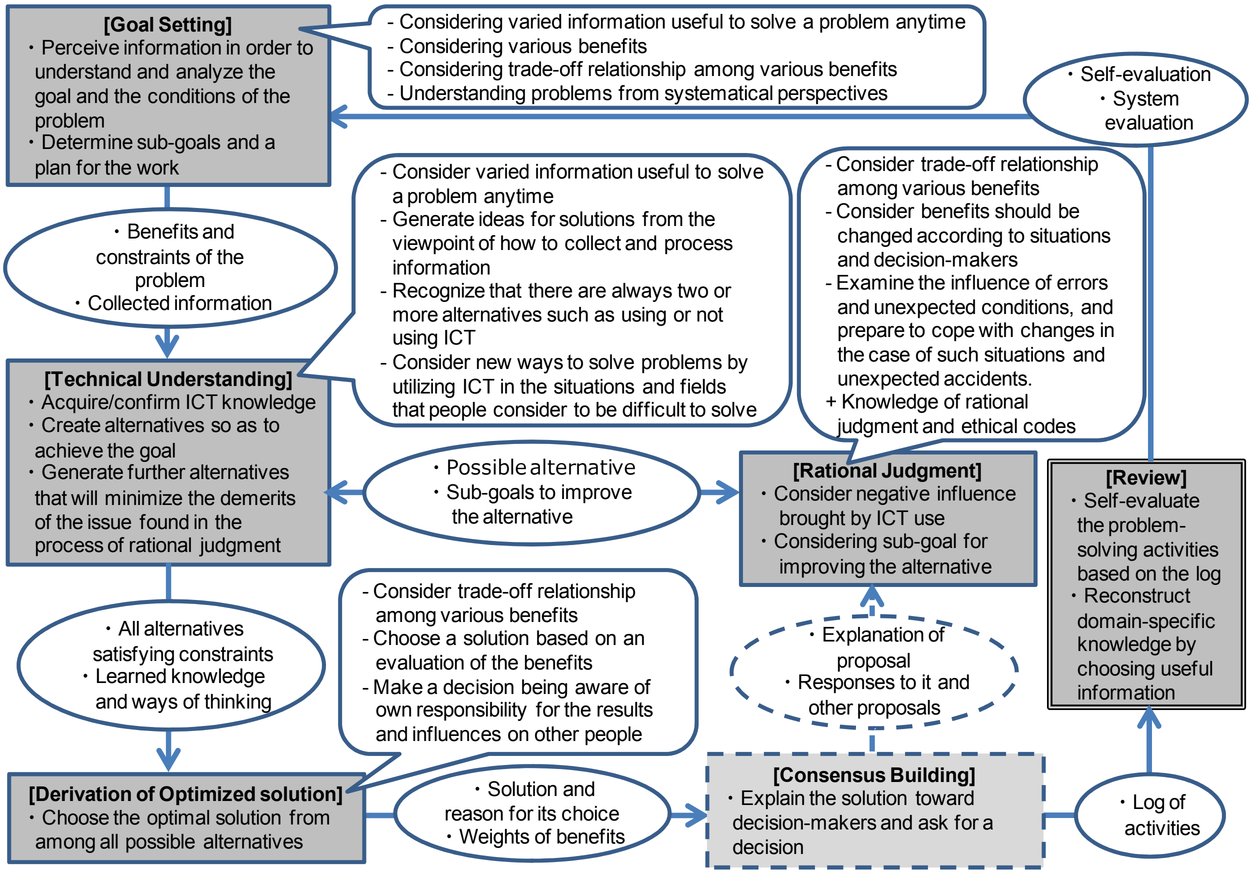

Figure 1. Matsuda's (2014) design framework of e-learning materials for information studies.

Purpose

In this study, we examine the teaching methods of exploration activities, and for this purpose, we develop an instructional gaming material to help students conduct such activities, as well as a design framework for gaming materials of exploration activities. To create the design framework, we examine which tasks and ways of viewing and thinking should be added to Matsuda's (2014) framework for scientific problem-solving. Additionally, we conduct a session using the instructional gaming material for students. We chose the topic of how to create an adequate plastic bottle word sculpture for a campus festival. We prompted students to consider methods of recycling plastic bottles and to choose an appropriate glue component and mechanism of construction in order to emphasize connections with learning outcomes of technology education and chemistry education.

Development of the Design Framework for Scientific Exploration Activities

Matsuda (2013a) stated that it is necessary to teach scripted knowledge of problem-solving, ways of viewing and thinking, and domain-specific knowledge to foster problem-solving abilities. His idea is based on Bruer's (1993) statement that general strategies, meta-cognitive skills, and domain-specific knowledge are all elements of human intelligence and expert performance. As mentioned previously, a framework of exploration activities in science should be similar to Figure 1. However, it is necessary to extend the activities to include scientific tasks and ways of viewing and thinking in each process. Therefore, we developed the framework shown in Figure 2 based on the following discussion.

Procedural Knowledge: Script Knowledge of Scientific Problem-Solving

Matsuda (2014) stated that the problem-solving framework belongs to general strategies, and then, it should emphasize the commonality of the problem-solving process within every subject area. The problem-solving process of Figure 1, shown as rectangle elements, was refined considering gaming materials for several domains. It also corresponds to the design process described in International Technology Education Association's (2007) technology standard and is sufficiently general and useful for problem-solving activities in daily life.

However, the tasks in each process are largely those necessary to consider how to utilize information and communication technology (ICT) in problem-solving activities. Therefore, we rewrote "technological understanding" as "generate alternatives." This change also avoids the possibility that "understand" will be confused with "understanding the problem" in the goal-setting process. Moreover, we changed "ICT" to "science and technology." However, this rewrite does not mean that exploration activities in science do not require the utilization of ICT. On the contrary, these activities should emphasize not performing laboratory experiments but collecting published data from the Webs, books, and so on. Therefore, "technology" in the revised framework includes ICT and informatic and systematic ways of viewing and thinking should be used in each process, in addition to scientific ways of viewing and thinking, as shown in the balloons in Figure 1.

Scientific Ways of Viewing and Thinking

Although MEXT (2009) stated that promoting students' utilization of scientific ways of viewing and thinking is one of the objectives of science education, it did not explain explicitly what these scientific ways of viewing and thinking are. Perhaps, MEXT's idea is that the ways of viewing and thinking are not teachable, but acquired naturally through performing scientific exploration activities. However, we do not support this idea, because it is based on behaviorism and is overly optimistic. As Matsuda (2013b) explained, ways of viewing and thinking should be taught explicitly as viewpoints or checkpoints that evaluate and conceive of solutions. Therefore, we adopt Matsuda's (2012c) scientific ways of viewing and thinking, as shown in Table 1.

Table 1

Matsuda's (2012c) Scientific Ways of Viewing and Thinking

(a) Examine hypotheses by means of experiments or observations.
(b) Consider a special case in which one of the factors is ignored or added.
(c) Deconstruct an experimental condition into various factors.
(d) Estimate the results of an experiment quantitatively by using hypothetical function.
(e) Examine whether the same results can be repeated.
(f) Plan an experiment focusing on examining a specific hypothesis.
(g) Examine consistency with known laws and facts.
(h) Consider the results that can confirm a hypothesis.
(i) Consider methods to change a specific factor of experimental conditions.
(j) Summarize the conditions or characteristics of phenomena focusing on their spatial properties.
(k) Summarize the conditions or characteristics of phenomena focusing on their timing of occurrence.
(l) Consider phenomena from the viewpoints of retention, transformation, and balance.
(m) Consider phenomena from the viewpoints of (dis)continuity and (ir)reversibility.
(n) Consider phenomena from the viewpoints of energy transaction and electrical property.
(o) Consider phenomena from the viewpoints of the structure of atoms and electron configuration.

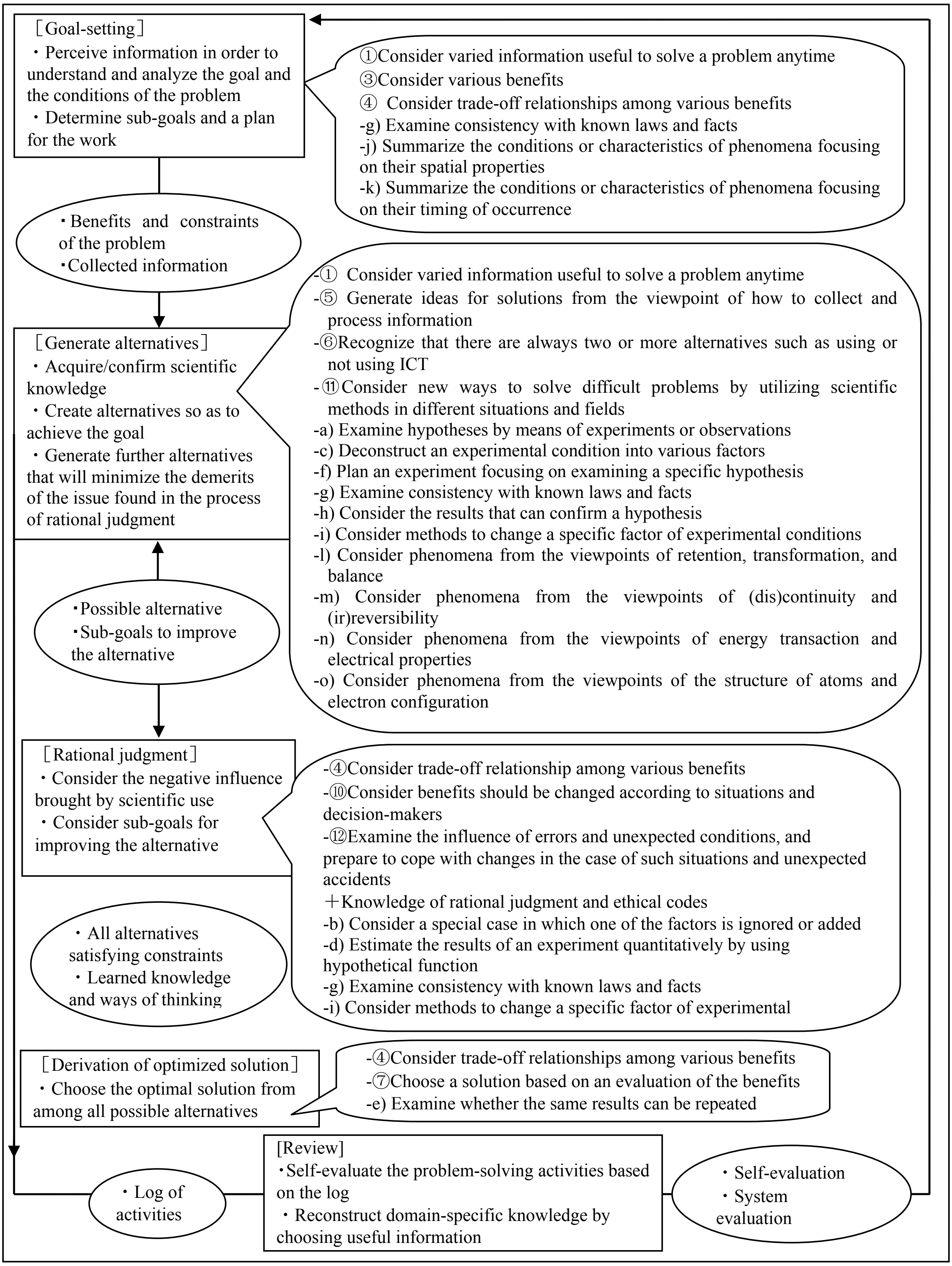

Figure 2. Our framework for designing gaming materials for exploration activities in science education.

Hereafter, we discuss which ones should be utilized in each process as well as their integration into the informatic and systematic ways of viewing and thinking shown in the balloons in Figure 1. To identify scientific problems and form hypotheses for scientific problem-solving, we should focus on differences and inconsistencies between phenomena and scientific facts or laws. Therefore, in the goal-setting process, as a special viewpoint for "understanding problems from systematic perspectives," we added (g) as a scientific way of viewing and thinking. From a similar viewpoint, we added (j) and (k) to find and summarize the purposes and conditions of problems systematically.

The main purpose of the "generate alternatives" process is to generate ideas or alternatives for examining hypotheses and understanding collected data. To generate ideas for collecting data for examining hypotheses, it is necessary to use appropriate scientific concepts or factors in confirming/acquiring scientific knowledge. To this end, (f), (g), and (h) are necessary. In addition, corresponding to the domain of problems, (l), (m), (n), and (o) must be used. Then, (c) and (i) are needed to analyze data or create a plan for an experiment. If no appropriate data can be collected, (a) should be used.

The main purpose of the rational judgment process is to critically review the results produced by the scientific understanding process. For this purpose, (b), (g), and (i) should be used. In addition, (d) may be useful to check the results quantitatively and inductively.

The main purpose of the derivation of an optimized solution process is to choose the optimal solution from among all possible alternatives based on the learner's reasoning performed in the generate alternatives process and rational judgment process. For this purpose, (e) should be used.

Development of an Instructional Gaming Material

In Japan, numerous instructional materials related to waste management issues have been developed, including many games (Matsumoto et al., 2009). However, these materials have the following issues:

1. Their target users are young children, and as such, the gaming format was selected to raise learning motivation by allowing users to compete to achieve the fastest time or highest score;

2. The purpose of these materials is to teach specific rules defined by a particular region, and then prompt users to separate many waste types into appropriate garbage bins;

3. Scientific and technological explanations concerning each garbage type (such as their materials, physical/chemical features, or disposal methods) are not given;

4. Insufficient feedback is provided when students make errors in separating garbage.

On the other hand, Japanese technology education textbooks include contents related to resources and environmental problems. However, as Yamashita and Iwamoto (2002) note, technology classes tend to focus on manufacturing activities and inadequately address how to reduce garbage production or reuse and recycle products. The present technology education is insufficient to cultivate students' problem-solving abilities that can adopt to a change of values, appearance of new materials, change of cost, possibility of reuse/recycle of each material, and so on, due to technological advancement.

Based on the above discussion, the gaming material based on Figure 2 was developed concerning how to create an adequate plastic bottle word sculpture for a campus festival. In this material, students are prompted to consider methods of recycling plastic bottles and to choose an appropriate glue component and mechanism of construction in order to emphasize connections with learning outcomes of technology education and chemistry education.

Flow of the Instructional Gaming Material

Goal-Setting Process

Based on Figure 2, the following goal-setting process for this material was designed. First, a student is assigned to a leader of the upper secondary school exhibition decoration team and provided with the project's mission. Then, according to the framework, he/she is expected to perform the first task: perceive information in order to analyze the problem. The necessity of this task is apparent if the student has acquired the way of viewing and thinking (i.e., considered varied information useful to solve a problem at any time). Moreover, a viewpoint for perceiving information is obvious if the student pays attention to the way of viewing and thinking (i.e., considers various benefits). If the individual possesses sufficient domain-specific knowledge about "various benefits," the burden of perceiving information can be reduced. On the other hand, if he/she assumes that only the word sculpture's attractiveness and cost are benefits, the issue of waste management will not be noticed. Therefore, the game must not mention waste management in this mission. Students should always perceive information positively to notice hidden issues and changes in states without depending solely on their prior or limited knowledge.

Here, the differences between games and gaming mentioned previously should be paid attention to. Instructional gaming materials prompt players "to learn through review after playing." Matsuda (2014) explained that the basic flow of information studies classes begins with an introductory exercise, followed by a lecture, and finally a retaining exercise. In an introductory exercise, students are expected to recognize the necessity of learning from failures. In a lecture, the knowledge and ways of viewing and thinking required to learn a problem are taught corresponding to failures in the introductory exercise. It is appropriate to apply such ideas even in this material.

According to the above idea, in order to provide students with opportunities to fail, instructors should ensure that they do not teach too much. However, if students with insufficient knowledge are not given clues, they cannot attribute their failure to achieve specific goals to themselves and consequently are not motivated to learn more. Therefore, it is imperative to embed clues into the information presented in various scenes. Moreover, it is necessary to prevent students from choosing correct answers by hurrying them to choose answers, exerting psychological pressure as other members' opposition, and so on. These principles for constructing choices and directions in gaming materials must be stated in the framework.

The first task in the goal-setting process (perceive information in order to analyze the problem) is designed as follows. First, a senior student gives the student a manual containing the following information:

(a) Drafts of word sculptures from previous years' campus festivals, as shown in Figure 3;

(b) Lists of materials that should be purchased to make each word sculpture;

(c) The location where the word sculpture will be installed (near the main gate), the size limit (about 1[m] × 1[m] for one word sculpture), formation (letters that designate the school name), and so on;

(d) There are two methods of assembling the word sculpture, as shown in Figure 4.

The above information suggests that the game requires students not only to primarily discuss the object's shape, but also to select assembly methods and connections. While some students may consider visual aspects to be most important, others may reflect on ease of assembly, durability, reduction in costs, and disposal of waste. It is important to provide students with opportunities to consider various benefits with minimum flexibility.

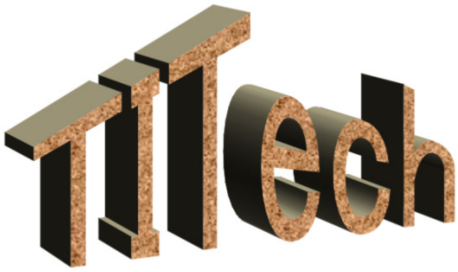

Figure 3. A draft of a word sculpture constructed for a past campus festival.

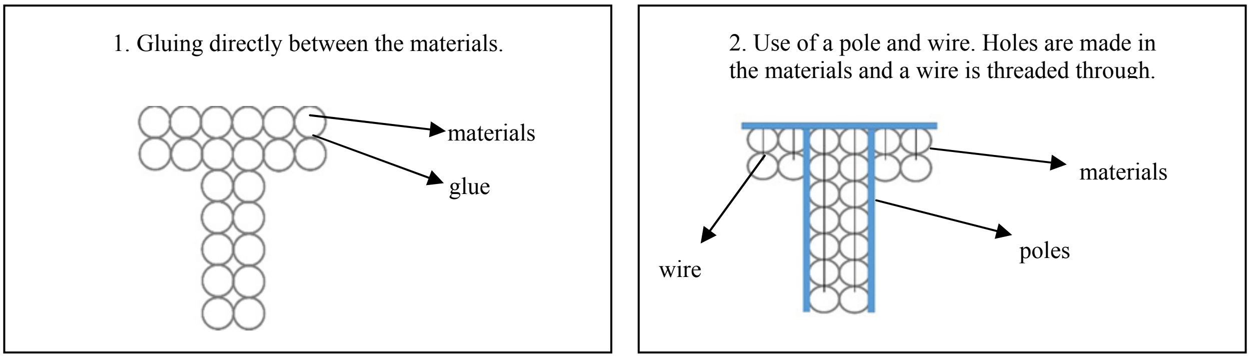

Figure 4. Two Assembly methods for the word sculpture.

The game discussed herein was designed based on Matsuda's (2015) idea that summarized the problem-solving process as a combination of warp process (goal-setting → technical understanding ←→ rational judgment → derivation of an optimized solution → consensus building → review) and woof process (collect → process → summarize). At first, when students collect information, they should have a purpose and may choose a specific information source for any reason (hypotheses). Moreover, Matsuda (2015) stated that students should utilize a chart as in Figure 5 to identify various benefits and related information resources.

This chart helps students formulate a problem by transforming it from various viewpoints and prompts them to utilize mathematical ways of viewing and thinking (i.e., specialization, analogy, and deduction) and informatics and systematic ways of viewing and thinking (i.e., considering varied information useful in solving a problem at any time). In this activity, we set a time limitation, because we assume that the activity time depends on each student. After that, they are required to collect information from "A directory of the campus festival," "A team teacher," and "A garbage disposal dealer." We provide the choices in Table 2, and as the choices contain both helpful and unhelpful information, students need to identify various benefits while understanding the messages and choices appropriately.

In the next task, students determine sub-goals and a work plan. To determine sub-goals, the students are required to choose sub-goals from various benefits generated in the previous task. These sub-goals become viewpoints for generating alternatives, while the other benefits become viewpoints for verifying the rational judgment process. Moreover, in this task, "I recycle plastic bottles" is added to the sub-goals by the students' selection or teacher's advice, because of the focusing activity.

After that, the students are required to devise a work plan, the order of viewpoints to generate alternatives, and a schedule. The latter emphasizes the necessity of adhering to a time limit in technological problem-solving. In this task, we provide the activities as follows: "Let us consider the procedure to efficiently propel work" and

"Let us consider the information resources to get the appropriate information." After that, the students are required to choose assembly methods. Based on these sub-goals and the work plan, students must generate alternatives in the next process.

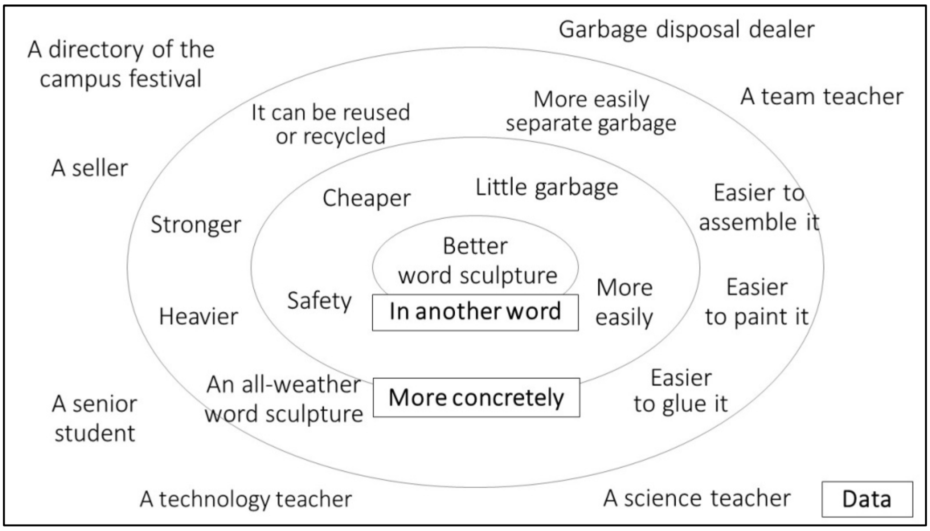

Figure 5. An example chart to help students formulate problems by transforming.

Table 2

Information Resources and Choices

Information resources	Choices
A directory of the campus festival	Opinion about a word sculpture from the last year
	Impression of a team member from the last year
	Impression of a senior student from the last year
A team teacher	Was there any trouble in the past?
	How big is the budget?
	Was the word sculpture popular in the past?
A garbage disposal dealer	What was the garbage disposal situation in the last year?
	Can you any advice on garbage disposal?
	Was there any trouble in the past?

Generate Alternatives Process

As mentioned previously, when students begin this process, they know the formation of the word sculpture and select the assembly methods. In the "Acquire/confirm scientific knowledge" task, students are required to acquire/confirm the following knowledge, although some should not be learned.

1. Knowledge concerning materials and connecting methods:

(a) Materials: plastic bottles;

(b) Connecting methods: aqueous, cyanoacrylic, cemedine, bond, hot bond/melt, and adhesives; packing, double sided tape, and colored adhesive tape.

2. Knowledge of recycling methods: Procedures and methods for recycling materials after they are used.

3. Knowledge of benefits that should be considered in choosing data collection and problem-solving methods:

(a) Websites containing useful data for examining several problems scientifically;

(b) Various beneficial points concerning problem-solving methods, the trade-off relationships among them, and ideas and viewpoints for conquering the trade-off relationship.

For the next task, students are required to generate alternative combinations of assembly methods and connection methods. Therefore, it is important to acquire knowledge concerning connecting methods for plastic bottles. Particularly, students must focus either on disposing of the garbage, so that it is reusable or on reducing its amount as much as possible. To accomplish this, students should be given an opportunity to consider conditions for disposing of the garbage, so that it is reusable. For example, in the case of a plastic bottle, if its vinyl label is peeled away following the drink's consumption, it can be recycled. However, if the plastic bottle contains a coloring agent or glue, it cannot be recycled until part of the coloring agent and glue is removed. This is noteworthy in relation to the second assembly method in Figure 4, wherein extra materials are not attached to the plastic bottles. Moreover, even if the first method is selected, some glue can be removed, assuming that students used an aqueous adhesive, although rain could possibly dissolve the adhesive if it is exposed to rain. Therefore, students should gather information concerning not only disposal methods, but also connection methods. In this game, students are not required to remember the properties of materials or connection methods. The domain-specific knowledge that students should remember are core concepts that can be used for general purposes in the domain, such as important keywords to use when searching Websites containing useful information related to connecting materials and waste disposal, while also utilizing knowledge concerning materials and recycling. Additionally, students should acquire knowledge to aid them in reading about, understanding, and judging information appropriately.

Based on the above, in this task, we prepared the following activities to collect and analyze information: "Let us research plastic bottle recycling methods," "Let us learn about the glue component and mechanism of construction," "Let us research a variety of connecting methods to use on plastic bottles," "Let us confine the variety of connecting methods," and "Let us research the quality and characteristics of connecting methods." Especially, in the activity of "Let us research the quality and characteristics of connecting methods," students are required to analyze information about the characteristics, usage, and price of connecting methods on Web pages prepared in the game. This activity requires the students to use scientific ways of viewing and thinking, such as "Consider phenomena from the viewpoints of retention, transformation, and balance," "Consider phenomena from the viewpoints of (dis)continuity and (ir)reversibility," and "Consider phenomena from the viewpoints of energy." Moreover, in this activity, they can research less than six of the 10 connecting methods shown in Table 3, because the game emphasizes the necessity of adhering to a time limit in technological problem-solving.

Table 3

Choices for Assembly Methods and Connecting Methods

Arrangement of word sculpture	Assembly methods	Plastic bottles	Connecting methods
(a) Horizontally (b) Vertically	(a) Gluing directly between the plastic bottles (b) Use of pole and wire. Holes are made in the plastic bottles, and a wire is threaded through.	(a) Shave (b) Do not shave	①Aqueous, ②Cyanoacrylic ③Cemedine, ④Bond ⑤Hot bond/melt, ⑥Packing tape ⑦Packing tape (color) ⑧Double sided tape ⑨Vinyl rope, ⑩Rubber

In the task entitled "Create alternatives so as to achieve the goal," students are required to generate alternatives. As mentioned above, the main purpose of this gaming material is to decide assembly methods and a connecting method. Therefore, initially, this task guides students to choose assembly methods and a connecting method from the choices in Table 3.

Rational Judgment Process

In this process, students should discuss the utilization of new technology and its social influences, risk evaluation, and trade-off relationships based on scientific reasoning. To perform risk and trade-off assessment, scientific problem-solving should emphasize logical judgments based on the reliability and validity of data according to scientific evidence and theories. To encourage students to examine issues and their alternatives, a framework for rational judgment is provided (Figure 6, left side) based on Tamada and Matsuda's (2004) framework used in Figure 1 for rational judgment in cyber ethics. This framework includes checkpoints that were not selected as sub-goals in the goal-setting process (Figure 6, right side). When students use the framework on the left, they must arrange choices concerning various benefits that are provided on the right. Additionally, if students cannot conclude whether there is problem, they should search for information independently or ask an expert. Based on the above discussion, the following rational judgment process was developed.

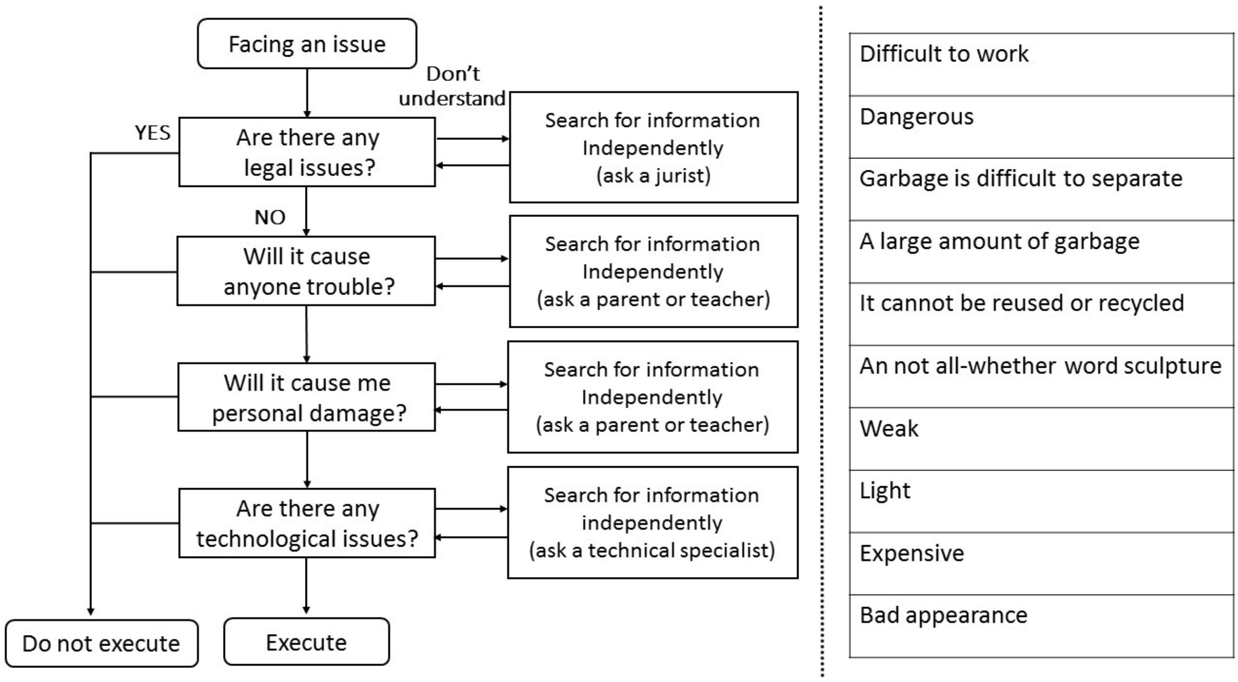

Figure 6. The rational judgment framework.

In the task entitled "Consider the negative influence caused by scientific use" students begin by examining issues related to alternatives they generated. As mentioned previously, it is here that students are prompted to identify issues of alternatives they generated according to the above framework using informatics and systematic ways of viewing and thinking. This includes considering the trade-off relationship between various benefits, determining which benefits should be changed according to situations and decision-makers, and quantitatively estimating the results of an experiment using hypothetical functions. If students identify issues related to alternatives they generated, they are prompted to consider sub-goals for improving the alternative using scientific ways of viewing and thinking (e.g., considering a special case wherein one of the factors is ignored/added or methods for changing specific factors in the experimental conditions). Students are then required to return to the generate alternatives process and reconsider alternatives in a task wherein further alternatives are generated to minimize faults found in the rational judgment process.

Derivation of an Optimized Solution Process and Review Process

In the derivation of an optimized solution process, students choose an optimal solution from among all possible alternatives using informatics and systematic ways of viewing and thinking (i.e., choosing a solution based on an evaluation of the benefits). Alternatives to choose in this task include “the word sculpture’s assembly method” and “connection methods.” Students must then explain the reasoning behind their choices by associating with benefits they chose.

In the review process of this gaming material, we explain that the main purpose of this gaming material to students. Firstly, we suggest that it is necessary to consider trouble to someone and environmental problems of manufacturing activities. Here, we emphasize the usefulness of the rational judgment framework. Secondly, we emphasize the time limitation in problem-solving again, as well as the importance of collecting and analyzing the information efficiently.

Checklist for Designing Gaming Materials for Exploration Activities in Science

In the development of the instructional gaming material based on Figure 2, many different designs were discussed, but most of them have been superseded, because they have some features and reasons to be improved. Therefore, we summarized the checkpoints that should be brought to attention in each process of the framework as well as the choice of a topic in designing gaming materials for exploration activities in science as shown in Table 4.

Table 4

Checklist for Designing Gaming Materials for Exploration Activities in Science

Topic	□ The topic is familiar to learners and motivates them to be challenged. □ The topic seems to be not concerned with science learning at a glance, but it is suitable to use the learning outcomes as devices to generate ideas to solve problems in daily life. □ The topic is not intended to teach new scientific knowledge, but to instruct learners how to solve problems scientifically while using learning outcomes of science education. □ The topic does not have a single correct answer. □ The topic requires more than literature reviews and laboratory experiments.
Process and main task	Checkpoints
Briefing session: (a) Understand the topic; (b) Understand the problem-solving framework; (c) Understand the scientific ways of viewing and thinking, and scientific knowledge as needed.	□ The mission is clearly explained. □ The problem-solving framework is explicitly displayed. □ The scientific ways of viewing and thinking are instructed according to learners’ situation. □ The minimum scientific knowledge required in the game is confirmed.
Goal-setting process: (a) Perceive information in order to understand and analyze the goal and the conditions of the problem; (b) Determine sub-goals and a plan for the work;	□ The goals and the conditions of the problem are confirmed. □ Various benefits and related information resources are identified by using a transformation chart before learners collect information. □ The information resources contain both helpful and unhelpful information. □ A variety of methods to collect information as well as their merits and demerits are recognized. □ “Sub-goals” are chosen from various “Benefits.” □ A work plan, necessary information, and their resources are considered in the task entitled “Determine plan for the work.” □ The time limitation is set to prevent much difference among learners’ progress.

(Table 4 to be continued)

Generate alternatives process: (a) Acquire/confirm scientific knowledge; (b) Create alternatives so as to achieve the goal; (c) Generate further alternatives that will minimize the demerits of the issue found in the process of rational judgment.	□ "Acquire/confirm scientific knowledge" is available according to learner's requests. □ The information resources contain both helpful and unhelpful information. □ No specific alternative is prompted to be chosen. □ An opportunity to create varieties of alternatives is provided. □ The sub-goals are clearly explained when learners create alternatives. □ The time limitation is set to prevent much difference among learners' progress.
Rational judgment process: (a) Consider the negative influence brought by scientific use; (b) Consider sub-goals for improving the alternatives.	□ The opportunity to omit an alternative out of conditions of the problem is provided. □ The opportunity to consider negative influence along with the rational judgment frame work is provided. □ "Benefits" not chosen as sub-goals are put into each viewpoint in the framework of rational judgment. □ The time limitation is set to prevent much difference among learners' progress.
Derivation of an optimized solution process: Choose the optimal solution from among all possible alternatives.	□ The optimal solution is not unique, but depends on each learner. □ The opportunity to explain the reason behind learners' optimal solution is provided.
Review process: (a) Self-evaluate the problem-solving activities based on the log; (b) Reconstruct domain-specific knowledge by choosing useful information.	□ Review information prompts a learner to reflect on activities so far in the game. □ Review information focuses on the most important activity for the learner in the game. □ Not only the result but also the process of the activity is guided to be self-evaluated. □ The system's evaluation focuses on the process of the activities rather than the solution. □ Questions are asked to collect additional information that could not be collected so far to confirm learners' thinking in problem-solving activities. □ Not only the scientific concepts but also the ways of viewing and thinking are promoted to be reconstructed.
Others	□ The activities in the game match the problem-solving framework. □ The ways of viewing and thinking are clearly explained. □ The time expected to finish the game is appropriately short for use in a lesson. □ The activities in the game correspond to differences among learners' progress.

Evaluation of the Instructional Gaming Material

Method

In December 2014, we conducted a trial lesson with the developed gaming material for 38 10th grade students (ages 15-16 years old) who were in one class at the Tokyo Tech High School of Science and Technology. In the school, all 10th grade students must take "Basic Physics" and "Basic Chemistry" in science. Moreover, they are required to take some compulsory technology subjects, such as "Information Technology," "Technology and Society," and "Technological Exercises and Science Experiments." Furthermore, they have already experienced the revised version of Ito and Matsuda's (2013) gaming material for PBL in mathematics.

The lessons lasted 50 minutes and consisted of the following steps:

1. The teacher explained the purpose of the lesson;
2. The students learned through the gaming material.

At the beginning and the end of the gaming material, we added a pre- and post- questionnaire, respectively, that consisted of the items shown in Table 5 rated on a 5-point Likert scale, from 1 "Disagree" to 5 "Agree," to represent their opinions.

Results and Discussion

All the students could finish this gaming material, and they responded to all items on the pre- and post-questionnaires. Therefore, in the following analysis, we used the data of 38 students. We indicate the average and standard deviation (*SD*) of each pre- and post- questionnaire item and *p*-value by the Wilcoxon signed-rank test in Table 5.

Table 5

Results of the Pre- and Post- Questionnaire

Questionnaire item	Mean (*SD*) of pre	Mean (*SD*) of post	*p*-value
Q1. I have confidence that I can solve problems along the problem-solving framework.	2.9 (1.1)	3.8 (0.9)	0.000
Q2. I think that it is important to utilize scientific ways of viewing and thinking for better problem-solving.	4.1 (1.2)	4.5 (1.1)	0.006
Q3. I think that I use the scientific ways of viewing and thinking.	3.0 (1.0)	3.7 (0.9)	0.002
Q4. I think that it is important to acquire scientific knowledge.	4.1 (1.5)	4.4 (1.2)	0.042
Q5. I think that learning outcomes of science are useful in my daily life.	4.1 (1.3)	4.6 (1.0)	0.011

In Table 5, regarding the acquisition of "scientific ways of viewing and thinking" (Q2 and Q3) that is the aim of this gaming material, there were significant differences at the 1% level between the pre- and post- questionnaire. These results suggested that the game encouraged students to utilize scientific ways of viewing and thinking explicitly. Moreover, regarding the recognition of "interest and utility in science learning" (Q4 and Q5) that is the aim of scientific exploration activities, there were significant differences at the 5% level between pre- and post- questionnaire. These results suggested that the game encouraged students to increase their interest in and feeling about the usefulness of science learning.

Moreover, there were significant differences at the 0.1% level between the pre- and post- questionnaire in Q1. We provided question item "X: Do you remember that this problem-solving framework was utilized before this session?" while suggesting the problem-solving framework for students before students began the project's mission in this gaming material, because they had already experienced the revised version of Ito and Matsuda's (2013) gaming material for PBL in mathematics. We analyzed the responses to Q1 in more detail (Table 6 and Table 7) by dividing the students into two groups; Group A consisted of 20 students who answered "Yes" for question X, and Group B consisted of 18 students who answered "No" for question X. The results showed that 11 students in Group A and 11 students in Group B had increased self-confidence after using this gaming material, and only 3 in Group B reported lower self-confidence. This suggests that the students acquired the problem-solving framework and became able to solve problems efficiently.

Table 6

Cross Table of Q1 (Pre-) × Q1' (Post-) in the Group of Students Who Remembered the Framework

Q1	Q1'				
Answer number	1	2	3	4	5
1	0	0	0	0	1
2	0	1	2	1	0
3	0	0	1	6	0
4	0	0	0	5	1
5	0	0	0	0	2

Moreover, we performed a log analysis of students' activities in the game as follows. Firstly, in the generate alternatives process of this gaming material, students are required to analyze information about the characteristics, usage, and price of connecting methods on Web pages prepared in the game. This task requires the students to use scientific ways of viewing and thinking, such as "Consider phenomena from the viewpoints of retention, transformation, and balance," "Consider phenomena from the viewpoints of (dis)continuity and (ir)reversibility," and "Consider phenomena from the viewpoints of energy." In order to judge whether the students in this study could utilize scientific ways of viewing and thinking appropriately, we asked them to choose any of the three sub-goals that are satisfied by the connecting method (see Figure 7). We analyzed their choices in this task and revealed that 20 students could judge information appropriately.

Table 7

Cross Table of Q1 (Pre-) × Q1' (Post-) in the Group of Students Who Did Not Remember the Framework

Q1	Q1'				
Answer number	1	2	3	4	5
1	0	0	0	1	2
2	0	1	1	4	0
3	0	2	1	1	1
4	0	0	1	2	1
5	0	0	0	0	0

<Acquire / confirm scientific knowledge>

②Cyanoacrylic

Characteristics	This glue forms the strongest bonds in tight joints between clean breaks or smooth surfaces. Best used with non-porous application parts such as metal and plastic. The glue bonds instantly, sets in seconds and is packaged in a long lasting 2 gram tube.
Works best on	Glass, Metal, Pottery, Plastic
Price	$2.00

Which sub-goals meet?
☐Safety
☐An all-weather
☐It can be recycled of plastic bottle
☐Dose not meet into any choices above

Figure 7. Example of researching the quality and characteristics of connecting methods.

Secondly, students' decisions in the derivation of an optimized solution process are shown in Table 8. Because we expected that the problem presented in this gaming material does not have a single correct answer, the result suggests that the problem of our game was adequate for scientific exploration activities.

Thirdly, our game used the timer function in many places to emphasize time limitation as well as to allow a play to be finished in a lesson hour. As shown in Table 9, all students could finish the gaming material within 50 minutes. On the other hand, we found a student who finished the game in 19 minutes. Therefore, we need to prepare an optional task, such as having the same mission but more constraints.

Table 8

The Optimal Solution of the Students

Connecting methods	The number of students
① Aqueous	6
② Cyanoacrylic	3
③ Cemedine	4
④ Bond	4
⑤ Hot bond / melt	7
⑥ Packing tape	2
⑦ Packing tape (color)	2
⑧ Double sided tape	0
⑨ Vinyl rope	8
⑩ Rubber	2

Table 9

The Time Required in This Game for Each Student

Time	～20	～25	～30	～35	～40	40～
The number of students	1	4	9	5	13	6

Notes. Minimal time is 19 minutes, and maximum time is 44 minutes in this gaming material.

Future Directions

In this study, we examined the teaching methods of exploration activities, and for this purpose, we developed a design framework for gaming materials of exploration activities to help students conduct such activities. Additionally, we developed a concrete instructional gaming material and conducted a trial lesson with it. As the result of the lesson, we confirmed that the game encouraged students to utilize scientific ways of viewing and thinking explicitly and to increase their interest and feel of usefulness in science learning.

As a future work, we should examine the appropriateness and flexibility of the design framework and checklist while developing another gaming material. Moreover, we should develop a teacher education course to promote teachers to use our framework for instructing Exploration Activities in science appropriately.

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