Instructional Materials for Cultivating Students’ Analogical Thinking Competency in Problem Solving and their Virtual Lessons to innovate Japanese Technology Teachers

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Abstract

Japanese technology teachers still tend to emphasize skill training in their lessons, although its focus in the national curriculum has shifted from vocational skill training to technology literacy for all. In order to support the innovations of technology teachers, this study intends to provide (1) excellent instructional materials for cultivating students’ technological and creative problem-solving competency and (2) ideal examples of lesson plans with their simulation on the virtual lesson system. In addition, we also need to provide the wider public with such instructional materials and lesson examples and obtain their strong support in order to make teachers change their consciousness.

Our instructional materials encourage students to find and examine alternatives to realize a specific purpose (function) under various situations. For example, we focus on “to transfer something” as a function, for example, “to carry materials,” “to supply energy,” and “to send data.” We can also change an object that is required to be transferred, such as a bag, snow, water, and a bird, in order to understand the relationship between the goodness of alternatives and the conditions of a problem. Moreover, we can set or change the conditions related to distance, time limit, tools available for use, upper limit of cost, etc. When we change these situations, our instructional materials help cultivate analogical thinking.

We believe that it is important to keep the period of each problem-solving cycle short and allow students to attempt many problems in similar but different situations. Moreover, students should be able to relate to the featured problems in their daily lives.

1. Introduction

1.1. Issues related to Technology Education in Japan

In Japan, technology education is provided to all students in the subject areas of “Industrial Arts and Home Economics,” especially in the areas of “Industrial Arts” at the lower secondary level and “Information Study” at the upper secondary level. Because the latter focuses on the information and communication technology (ICT), our study intends to develop the former.

As Matsuda (2006) reported at the PATT-15 conference, the Japanese national curriculum of Industrial Arts has shifted its focus from vocational skill training to technology literacy for all. However, school teachers still emphasize skill training in their lessons. Therefore, teachers’ professional development is the most important factor in improving technology education in Japan. For this purpose, we believe that it is
necessary to provide excellent instructional materials and ideal examples of lesson plans that support teachers’ innovations. In addition, we also need to provide the wider public with such instructional materials and lesson examples and obtain their strong support in order to make teachers change their consciousness.

1.2. Analogical Thinking in Problem Solving

Instructional design theories assumed that there are five categories of learning outcomes, namely, intellectual skills, cognitive strategies, verbal information, motor skills, and attitudes. Problem solving is the highest order goal of intellectual skills and is defined as the ability to adopt rules/principles and concepts in order to solve new problems by analyzing the situation and formulating plan (Gagne et al. 2005). An instructional strategy adopted to cultivate problem-solving abilities is either discovery learning or guided discovery learning. This implies that the instructional strategies for problem solving mainly comprise “eliciting performance” and “providing feedback on performance correctness,” in addition to “providing learning guidance” for guided discovery learning, as indicated in Gagne’s 9 events. However, this idea does not clarify why some students acquire problem-solving ability and some do not. In addition, the most important factor in cultivating problem-solving ability does not relate to whether or not students can solve a particular problem by themselves; it relates to whether or not they can apply this ability in solving other problems. We believe that the purpose of technology education is to encourage students to solve similar problems in their lives.

The instructional design theory also assumes that cognitive strategies play an important role in problem-solving activities. However, since they are considered to be domain-specific, their instructional methods are yet to be studied with respect to each subject area. Therefore, we proposed “views and ways of thinking” as a cognitive strategies for problem solving in subject areas such as mathematics (Matsuda 2008) and information study (Matsuda et al. 2008). In addition, Uchino & Matsuda (2007) proposed an instructional strategy to promote analogical thinking as a general cognitive strategy. We believe that in order to cultivate students’ ability in technological problem solving, it is important to (1) teach students how to think in technological and systematic terms and (2) introduce activities that inculcate this way of thinking in students. In addition, our instructional materials emphasize cultivating analogical thinking.

2. Purpose

This study develops (1) instructional materials for cultivating students’ technological and creative problem-solving competency and (2) the virtual lesson system that features lesson simulation in which our instructional materials are utilized. For this purpose, this study uses the Instructional Activities Game (IAG) developed by Matsuda (2004). The reasons that we use the IAG system are as follows: a) As assumed by the instructional design theory, the basic strategies for cultivating problem-solving ability
are “eliciting performance” and “providing feedback.” Therefore, we consider that it is better to adopt the
gaming simulation technique to our instructional materials, and the IAG system enables the development
of such materials as well as other instructional materials that provide fundamental knowledge.
b) Our instructional materials are expected to be used in school lessons. As previously stated in (a),
feedback plays a central role in cultivating problem-solving ability. However, it is difficult to prepare
different forms of feedback in our instructional materials. The best solution to this problem is
collaboration. The IAG system has collaboration functions that control the progress of learning and help facilitate a discussion along with the utilization of learners’ responses in the game.
c) We believe that it is necessary to (1) encourage teachers to conduct ideal lessons and (2) provide them with ample opportunities to develop their skills. The IAG system has the function to perform virtual lessons in order to provide teachers with the opportunity to develop their lesson skills. It also provides an opportunity to the wider public to learn about our ideal lessons, thus obtaining their strong support in order to make teachers change their consciousness.

3. Instructional Activities Game (IAG) System

The IAG system was developed as a tool for incorporating teacher training and research into teaching (Matsuda 2004). The system has two game modes. One mode, referred to as the decision making game (DMG), was originally developed as a replacement for the “stop video method” introduced by Yoshizaki (1983), which was proposed to analyze the characteristics of teachers’ decision making in lessons. Because a DMG game board consists of a set of states corresponding to the individual cells of a board game, the DMG mode has been used to develop and execute several instructional materials beyond its original purpose. The other mode, referred to as simulated teaching game (STG), was developed for evaluating lesson plans designed by users and developing teachers’ competency to conduct better lessons as a replacement for “microteaching” by Allen and Ryan (1969).

Although DMG and STG work differently, as most of the game board elements are the same, as shown in Figure 1, both the modes are integrated in the IAG system. The DMG game board consists of a set of states that are described by a combination of the following: (1) state ID, (2) questions for users, (3) dialogue interface and options, (4) rules for determining the next state, (5) rules for updating variables, and (6) rules for providing feedback. The game board has a special state named “INIT” for declaring global variables in addition to their initial values and for designating the start state. In each state, the DMG initially generates a Web page using “question for users” and “dialogue interface and options,” as is shown in Figure 1. Many types of dialogue interfaces are commonly employed in both STG and DMG, such as RADIO/CHECK/SORT, TEXTBOX/NUMBOX/MATHBOX, MAP/VMAP/CHECK-MAP/VCHECK-MAP, TABLE, and COMB, which are created using HTML. In addition, C(oncept)-MAP and PHYSICS are supplied as Java Applets. The user response and the values of variables are pattern-matched with the rules for updating
variables, providing feedback, and determining the next state. In order to describe the rule for determining
the next state, “end” and “self” can be used for designating “game-over” and “repeat the same state.”

In this study, a newly developed function for DMG (Matsuda 2009), namely, the lesson support function,
is utilized in order to realize cooperative learning facilitated by a teacher as well as utilize individualized
instructional materials. This function enables a teacher to (1) set “stop states,” wherein learners cannot
progress to the next state until the teacher unlocks the state and (2) set “summarize states,” wherein he/she
can summarize the learners’ responses and display the results of classroom discussions.

Figure 1: Operation of DMG and STG based on an Example Game Board and a Lesson Plan

The STG game board represents a set of production rules. Each rule is described by a combination of the
following elements: (1) rule ID, (2) conditions for rule activation, (3) message for users, (4) dialogue
interface and options, (5) rules for updating variables, and (6) rules for providing feedback. Elements (3) to
(6) belong to the action aspect of the production rule. When a user logs onto the STG, the game first reads
the user’s lesson plan. A lesson plan comprises a sequence of sections chosen in the lesson flow analysis.
Moreover, each section has its own learning objectives and is planned as a sequence of steps that consist of
the following five elements: prediction of learners’ situations, instructional intentions, method of
communication, lesson content, and changes in learners’ situations. Once the lesson plan is read, the game
flow is controlled by the step data of the lesson plan, as described in Figure 1. At each step, information regarding the five elements with inner variables, which are used to represent learners’ situations or retain users’ responses, are saved in the working memory by the system. These are then compared with the “conditions for rule activation” in the game board. On the activation of a rule, its corresponding action aspect will then display messages as a lesson event, ask for a response, update the inner variables, and/or provide feedback as advice or as a result of his/her decision. If, at any step, two or more rules match the information in the working memory, a meta-rule defined in the system determines the order to be activated. After processing all rules corresponding to the current step, the STG repeats the process. Similar to the DMG, the STG requests the special rule “INIT” in a game board for declaring the global variables and the tag names of five elements in each step of a lesson plan, if they are used to match with the conditions for rule activation.

4. Design of Instructional Materials

4.1. Strategies Adopted in our Instructional Materials

Our instructional materials are developed by integrating the following three instructional design theories and ideas: “Zoom Lens Model (Reigeluth 1979),” “Goal-based Scenario (Schank et al. 1999),” and “Learning Communities in Classroom (Bielaczyc & Collins 1999).” Moreover, we adopt the instructional strategy that promotes analogical thinking by using the IAG system (Uchino & Matsuda 2007).

“Zoom Lens Model” is one of the elaboration theories that determine the scope and sequence of instructional materials. It emphasizes the appropriate integration of the bottom up approach and the top down approach; in other words, it emphasizes the relationship between goals/application and fundamentals in order to retain the motivation of learning and to promote holistic understanding. We believe that it is important to keep the period of each problem-solving cycle short and allow students to attempt many problems in similar but different situations. We aim to put in efforts to cultivate the competency to utilize different ways of thinking in finding a better solution, rather than to develop the skills for creating products. We expect that the “Zoom Lens Model” is suitable to our ideas.

The “Goal-based Scenario” also emphasizes the motivation of learning, and it stands on constructivism. Typically, an instructional material, which conforms to the GBS theory, takes the style of a serious game that requires learners to accomplish certain missions such as formulating an eco plan to save energy and resources at home for reducing the emission levels to 16% below the 2005 levels and to find a sufficient number of blood donors in order to help a family member who needs to undergo an urgent operation. In our instructional materials, students are encouraged to find and examine alternatives to realize a specific purpose (function) under various situations. For example, we can focus on “to transfer something” as a function, for example, “to carry materials,” “to supply energy,” and “to send data.” If one wishes to send money, one can send it by either carrying bills or using money transfer (transforming bills to data and data
to bills). Furthermore, one can change an object required to be transferred, such as a bag, snow, water, a dog, and a completed jigsaw puzzle, in order to understand the relationship between the goodness of alternatives and the conditions of problems. Moreover, we can set or change the conditions related to distance, time limit, tools available for use, upper limit of cost, etc. Our instructional materials emphasize cultivating analogical thinking.

The GBS theory assumed that learning through gaming occurs when learners play the game. However, Duke (1974) suggested that the purpose of gaming simulation is to support communication among people who have different models in mind and to display the results of their interaction. Therefore, gaming simulation methods require setting the debriefing process after playing a game in order to discuss about and learn from gaming. For this purpose, it is necessary to provide students with the opportunity to learn collaboratively by sharing their experiences in a game with others. As per the utilization of the lesson support function of the IAG system described previously, teachers can facilitate collaborative learning by sharing the responses in our instructional materials.

4.2. Elements and Sequence of our Instructional Materials

In Japan, there are two types of textbooks edited and published by private companies after being supervised by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT). One of them (Kato et al. 2007) shows the general problem-solving process, manufacturing (making products from woods, metals, and plastics), making products that apply energy transduction, problem solving by utilizing ICT, and producing multimedia content, as is shown in Figure 2.

![Diagram of Different Process of Technological Problem Solving](image)

**Figure 2**: Different Process of Technological Problem Solving Presented in a Textbook

Although technology education intends to cultivate students’ problem-solving ability, we anticipate that it is difficult for students to understand the commonality among these processes as problem-solving activities. Therefore, we assume a common framework of problem-solving activities, as is shown in Table 1. In this table, the processes from left to right—(1) to (4)—correspond to the general problem-solving process that directly improves the quality of products, and the processes from top to bottom—(a) to (c)—
correspond to the problem-solving process by utilizing ICT that indirectly improves the quality of products by improving the quality of problem-solving activities. Because the use of ICT in a cell also requires processes (1) to (4), these processes are recursively repeated if students do not acquire the default procedure. Therefore, the use of ICT is more fundamental for students.

The flow of our instructional materials is as follows: (1) an exercise in order to make students understand why they need to learn about problem solving (Figure 3), (2) learning about each topic and way of thinking (Figure 4), and (3) exercises for retention (attempting the same problem) and transfer (analogue problems).

### Table 1: Integrated Framework of the General Problem-solving Activities and by Utilizing ICT

<table>
<thead>
<tr>
<th>Stage</th>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Gathering information</td>
<td>Finding the purpose. (Knowing the goodness.)</td>
<td>Finding the new materials and methods to process alternative to the known ones. Generating alternatives. Collecting information to buy parts and tools.</td>
</tr>
<tr>
<td>a)</td>
<td>Analyzing the situation. (Knowing the conditions to consider in general.)</td>
<td>Checking the difference between the plan and the present state. Finding a method to resolve issues. Generating alternatives.</td>
</tr>
<tr>
<td>a)</td>
<td>Finding the materials and methods to process.</td>
<td>Reviewing the plan. Describing the problems and their reasons.</td>
</tr>
<tr>
<td>b) Processing information</td>
<td>Associating the goodness of product/proof with the features of materials and methods. Considering the trade-off relationship among the goodness.</td>
<td>Calculating the cost of each alternative. Examining the risks and problems anticipated in adopting each alternative. Evaluating the alternatives and choosing one of them.</td>
</tr>
<tr>
<td>b)</td>
<td></td>
<td>Estimating the effects and costs of each alternative. Evaluating the goodness of each alternative.</td>
</tr>
<tr>
<td>b)</td>
<td></td>
<td>Examining the decision rules that should be improved. Simulating the results if some rules are improved or added.</td>
</tr>
<tr>
<td>c) Presenting information</td>
<td>Defining a problem with the agreement of a target function and constraints.</td>
<td>Drawing drafts. Making an operation schedule and clarifying the points to be checked.</td>
</tr>
<tr>
<td>c)</td>
<td></td>
<td>Recording the changes and their reasons to be reflected in the next process.</td>
</tr>
<tr>
<td>c)</td>
<td></td>
<td>Making a report and sharing information in a group.</td>
</tr>
</tbody>
</table>

![Figure 3: An Example of the Problem-solving Game](image)
In order to carry something, various things, such as a shopping bag of a store, an envelope, a bag, and a carton box, are used. Although these containers are made from various materials, what types of materials can you imagine, in addition to the following materials? “Papers,” “Vinyl & plastics,” “Cloth & skins”

Which materials are suitable in order to make containers for carrying fruits [flower, juice, paint, fish, bird, and snow]? ○ ○ △ ×
- Papers
- Vinyl & plastics
- Cloth & skins
- Glass

Are the materials with which you considered making containers sufficiently suitable to transfer or carry the things shown in the previous problem? If you can imagine another material in addition to the following ones, please state it here. “Papers,” “Vinyl & plastics,” “Cloth & skins,” “Glass”

In some cases, heat-retention, breathability, and softness may be needed for containers. How is each feature realized?
- Changing the thickness
- Changing the quality of materials
- Choosing a method of surface processing
- Forming structure
- Others

We can make many types of containers from different features of papers manufactured by different methods of processing. What is the difference among envelopes, carton boxes, milk cartons, and paper handbags, considering that they have a common feature of “made from paper” and being “containers used to carry or transfer a thing”?
Papers differ in thickness, quality of their fiber, strength, method of surface processing, and water resistance among envelopes, carton boxes, milk cartons, and paper handbags. We shall classify these differences into “intended features” and “methods of realizing intended features.”

Figure 4: A Part of an Instructional Material that Explains Each Topic and Different Ways of Thinking
(Collaborative Learning is conducted at Each Step Represented by a Bold Line)
5. Virtual Lesson System

In order to conduct virtual lessons on the IAG system concerning the use of a general-purpose STG game board, only the data of a lesson plan described in the format of Table 2 is necessary, although it should be finally transferred to the list format. Unfortunately, because this game board does not support the simulation function of DMG games, that is, the function to simulate DMG games described as lesson plans in the STG game mode, users should simultaneously access both the virtual lesson game and the instructional material. In contrast, because this approach simplifies the lesson plans, i.e., the lesson plans do not include DMG game sections, it emphasizes the similarity of lesson style and decreases the cost incurred in transferring instructional materials described as DMG games to lesson plans for the STG mode.

<table>
<thead>
<tr>
<th>Learners’ Situations</th>
<th>Instructional Intentions</th>
<th>Method of Communication</th>
<th>Lesson Contents</th>
<th>Responses and their treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>- before the lesson starts</td>
<td>- prepare for the lesson</td>
<td>other [starting a game]</td>
<td>(game “admin” “passwd” “ini-file.ini” “/admin-url”)</td>
<td>Checking /ID-ADMIN and examine your IP address</td>
</tr>
<tr>
<td>- coming into the room</td>
<td>- prompt students to prepare</td>
<td>show on the blackboard [speak loudly]</td>
<td>“Switch on your computer and switch off the display.”</td>
<td>Walking around the room and direct anyone who didn’t switch on his/her computer.</td>
</tr>
<tr>
<td>- sitting down in front of a computer</td>
<td>- prompt students to hear</td>
<td>using ICT [presenting by PowerPoint]</td>
<td>“Please look at the screen. Yesterday, I received a box of fruits sent by delivery service.” [slide 1]</td>
<td>Warning anyone who does not pay attention to the screen.</td>
</tr>
<tr>
<td>- not paying attention</td>
<td>- not interested in today’s topic</td>
<td>direct [speak loudly, to all]</td>
<td>“Let’s log onto the game. Don’t use the backward button of your browser!”</td>
<td>Checking URL, ID and password if anyone can’t access the game.</td>
</tr>
<tr>
<td>- increasing the gap of progress in the class</td>
<td>- set a time limit</td>
<td>Ask [speak loudly, to all]</td>
<td>“Now about xx minutes remain. Have you selected a delivery service provider?”</td>
<td>Checking states of progress and giving advice to anyone who is late.</td>
</tr>
</tbody>
</table>

6. Summary and Future Perspectives

In this article, in order to support the innovations of technology teachers, we designed and developed an example of instructional materials for cultivating students’ technological and creative problem-solving competency. In addition, we provide an ideal example of lesson plans with their simulation on the IAG system. Our instructional materials are developed on the basis of the integrated framework of general problem solving and by using ICT. Because technology education in Japanese lower secondary schools is
not provided in an independent subject area, but in “Industrial Arts and Home Economics,” learning about technology from the consumer’s viewpoint is more important than learning about it from the manufacturer’s view. Moreover, the relationship between problem-solving activities in traditional technology use and those using ICT should be emphasized because technology education is provided only in Information Study at the upper secondary school level.

Although we developed an example of instructional materials and lesson plans, we did not examine their feasibility and effects. Therefore, we are planning to conduct formative evaluation at an open laboratory event of our university held in this October, which was attended by many people ranging from primary school children to people aged over 60. In addition, after developing the basis of formative evaluation, we plan to conduct trial lessons both at our attached high school of the Tokyo Institute of Technology and at a public lower secondary school.

References

Reigeluth, C. M. (1979). In Search of a Better way to Organize Instruction: The Elaboration Theory.

