An Open-Ended and Interactive Learning Using Logic Building System with Four-Frame Comic Strip

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Abstract. This paper reports an interactive system for learning by logic building. In the system, a learner is requested to build multiple logic patterns to explain a given four frame comic strip in multiple ways. The system can diagnose the build logic patterns and provide immediate feedback with semantic reason related to the strip. We show the effectiveness of the proposed system by using experimental results that were obtained through a use of the system by elementary school students.

Keywords: Critical thinking · Educational system · Logic · Four-frame comic strip

1 Introduction

The "21st-century skills" have been proposed as indispensable skills to participate in an active global society [1] and many countries are currently undertaking implementation. The definition includes ten skill groups in four areas (ways of thinking, ways of working, tools for work, and ways of living in the world). The "critical thinking" skill in the "critical thinking, problem solving, and decision making" group is considered to be important for the future. Critical thinking is defined by Zechmeister et al. as "logical, unbiased thinking based on appropriate standards and reasons" [2].

Many researchers have pointed to the importance of a multi-perspective thinking style and being able to grasp multiple aspects of the given information and knowledge [3–5] but creating exercises for developing that capability is not easy. We have already developed an open-ended, interactive logic building learning system that enables logical thinking about four-frame comic strip content from multiple viewpoints. Practical use of this system in an elementary school is also reported.

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2 Related Work

2.1 Importance of Multiple Viewpoints in Critical Thinking

Suzuki et al. define critical thinking as "the capability and attitude of careful, logical analysis of given information and knowledge rather than accepting it without thought" [3]. Michita position critical thinking as a problem solving process that includes (1) problem discovery, (2) solution search, (3) solution evaluation, and (4) conclusion, and defines it as seeing through to the essence of a problem by understanding multiple aspects without being confused by the obvious [4]. These definitions include the concept of multiple viewpoints, and step 2 of the process described by Michita particularly emphasizes the need for capturing multiple aspects of a problem.

Zechmeister et al. also hold that an 'open mind' is a characteristic of persons that engage in critical thought. This open-mindedness is expressed as a behavior in which unbiased judgements are made by viewing a thing in both good and bad aspects and considering it from all points of view rather than simply one or two perspectives. Zechmeister and Johnson [2] describes a four-step critical thinking process that involves (1) clarification, (2) investigation of the basis for reasoning, (3) reasoning, and (4) decision to act. They further describe a higher-level metacognitive process that performs look-back control to check for the correct execution of the four steps, and the necessity of an objective and multi-perspective attitude in steps 2 through 4 [5]. Michita also describe "the necessity of understanding something before critiquing it" and "critique without (an effort for) sufficient understanding is nothing more than simple misunderstanding with the identification of faults and other essential elements of critical argument removed". They also point to the importance of a favorable understanding in critical thinking [6]. Taking other logical structures to be correct for the moment is nothing other than multi-perspective thinking.

2.2 Training for Logical Thinking

Logical thought is important in critical thinking. It is required in step 3 of the process proposed by Michita [4] and in the first three steps of the process proposed by Kusumi [5], which are both described in Sect. 2.1. The capability for logical thought must be cultivated to achieve logicality in critical thinking, and the Toulmin model is often adopted for that purpose. In the Toulmin approach, the outcome of an argument obtains from the arrangement of a proposition and statements (layout method), which requires a particular form of argumentation [7]. Specifically, a claim C requires supporting grounds D and a warrant W to provide a reason that C can be claimed on the basis of D. There is also qualification Q that represents the reliability of the warrant, rebuttal or reservations (unless…) R, and backing B that supports W. There is research on writing composition that introduces this argument form [8, 9]. The objective of that research is to promote logical thought.

With the objective of fostering the development of capabilities for conceptualization, logical thinking, expression, critical thinking, and communication, the Finnish approach to education has been studied and introduced [10, 11]. That approach

emphasizes reason-based teaching, and uses lessons that involve making mind maps with Carta, writing composition lessons that use formats, and other such methods.

All of that research presumes time-consuming reading and writing of documents that is difficult to do repeatedly. That makes it difficult to try various logic structures or to make sense of strange logical structures. Here, we propose a method for building logics in which a four-frame comic strip is used as the layout and short sentences written on cards are arranged. This approach makes it possible to implement learning activities in which students can try various logical structures and make sense of them.

2.3 Research Using Four-Frame Comic Strips

The advantages of using comics as teaching materials listed below were suggested by Michita [12].

(a) They are fun and motivating.
(b) Ideas can be expressed briefly and simply. Four-frame comic strips in particular generally consist of a logical narrative development, such as introduction, development, turning point, and conclusion.
(c) The exposition is not entirely by words, so the reader is free to apply language and reason on their own beyond the text.
(d) There is no problem of privacy.

Our work uses advantages (b) and (c) from the above list. Specifically, concise presentation of ideas and logical development are used in logic building exercises. Using advantage (c), learners are free to interpret the comic strip frame by frame, so logic-building exercises in which the learner can build logical structures from multiple viewpoints can be designed.

Our reasons for introducing four-frame comic strips can thus be summarized as follows.

(a) The logical development for reaching a conclusion is included.
(b) The content is limited and concise.
(c) It is easy to think with focus on the logical development itself.

Furthermore, because there is no dialogue or explanation,

(d) The learner has freedom in interpreting each frame, allowing various logical developments to be considered.

That is to say, the learner can freely build logical developments while attention is restricted to the pictures drawn in the four-frame comic strip.

The result is that

(e) Exercises for building a variety of logics can be systematically constructed.

Previous work using four-frame comic strips can be broadly classified as follows.

(a) Research on using comic strips as a means of presenting communication and educational content: various fields

(b) Research on setting topics for eliciting explanation of the drawn content in comic strips: Japanese language education, medicine
(c) Research on the comic strips themselves: literature, cultural anthropology, etc.
(d) Research on using comprehension of comic strips as grounds for distinguishing humans from machines based on the advanced thinking capability required for understanding comic strips: log-in authentication
(e) Research that introduces the creation of comic strips as a learning subject: education

The work we report here concerns categories (b) and (d) in the above list. Advanced research in category (b) involves the use of four-frame comics as teaching materials for foreign students learning Japanese and as materials for identifying learners who have neurological or sensory disabilities. Our work targets healthy Japanese elementary school students. Research in category (d) concerns methods of using high human cognitive abilities as filters to prevent unauthorized log-in to on-line services by computer programs. Our work also deals with advanced thinking, but our purpose differs from previous research in this area. Category (b) also includes work on identifying patterns of story development in existing comic strips [13]. Our research separates the patterns into three types according to the relationships between frames. Differences in the interpretation of each frame enable greater variation in logical development.

3 Proposed Learning Method

In this paper, a learning task that requires a learner to build several logic patterns for a four-frame comic strip with a set of components of the strips. Because the components and the ways to connect have been specified previously, it is possible to diagnose the build one. We call this framework kit-build framework [14]. Kit-build framework is promising to realize interaction for a task that required a learner to build something by him/herself. We have already implemented practical learning environment for problem-posing arithmetic word problem [15] and concept map for scientific knowledge [16].

3.1 Learning Task and Method

First, the system presents one comic strip (with dialog or other textual explanation removed) and a set of cards on which explanations of one or a few sentences are written. The learner first reads those and then arranges the cards to match the frames to which they are appropriate. In each task, at least eight cards are presented so that multiple cards might be assigned to one frame. Assigning multiple cards makes it possible to create multiple logical developments.

The assignment of cards to frames is followed by construction of logical developments. In this step, cards are selected for each frame and arranged in order so that the four frames are logically linked to build a logical structure. The system provides immediate feedback with semantic reason. When the student gets it wrong, he is

required to improve the incorrect story until it becomes correct one. If the built story is correct, the student is requested to build other logical story for the same comic if the number of storied that student built for the strip is not enough. This process with respect to the same comic are repeated several times. A student builds several logical stories with respect to the given four-frame strip. We believe that this process can be used to implement learning activities for building multiple logics from the same target.

3.2 Open-Ended Interactive Environment

The concept of logical development in a four-frame comic strip is illustrated in Fig. 1. The four-frame comic strip that is presented has had dialog and explanation removed and consists of images only. The logical developments include both complete and partial series that are consistent with the final frame. Introducing pictures that have no dialog or explanation allows various interpretations to be made frame by frame, so the learner can compose logical developments by selecting cards in any order according to their own interpretation. For example, considering that there are ${}_{10}P_4 = 5040$ combinations for constructing logics from 10 cards for a single four-frame comic strip, if there are five correct solution patterns, then the probability of obtaining a correct solution by chance is 1/1008. In the sense that the learner can arrive at multiple correct answers from those various interpretations, this can be said to be an open-ended environment.

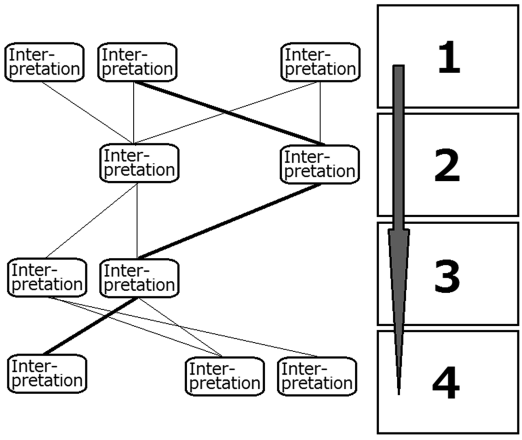

Fig. 1. Logical development in a four-frame comic

Because the system provides the components for constructing logics, it does not give the learner complete freedom in thinking. We nevertheless believe that it does allow sufficient freedom for the purpose of enabling to learner to consider different logics for the same target by making it possible to provide a search space that enables the sort of trial-and-error thinking described above. Restricting freedom to a certain extent in this way also is also expected to stimulate learner activity. That is to say, we believe that

providing components and limiting interpretation might itself promote logical thinking by the learner. As a result, we can expect that the learner will be able to arrive at more interpretations and logical developments than would be possible with completely free thinking.

The system determines whether or not a correct logical development is included in the card arrangements made by learners and provides immediate feedback, thus implementing interactive logic-building exercises. The system also collects information on learner behavior and intent, such as which buttons and cards are selected, thus indicating which problems were attempted, which cards were selected, how cards were ordered, and the extent to which different logical patterns were challenged. That information is then used to select which exercises are presented to the learner. Logging into the system with the same ID allows learners to continue an exercise where they were when they last logged out. To motivate learners, medals are awarded according to the correctness and patterns of the assembled logical developments. These features also contribute to the interactivity of the environment.

3.3 The Learning System

We designed and developed a system for practicing the learning exercises described in Sect. 3.1. The materials for an exercise include a four-frame comic strip and a set of cards for constructing logical developments for the comic strip. Materials for seven exercises were prepared.

Learners can log into the system with individual IDs and passwords that were given to them. Immediately after logging in, the learner can select the problem level 1 or level 2. It is recommended to start with level 1, which is simpler and presents fewer cards.

Once a level is chosen, the display changes to the problem selection screen (Fig. 2). Below each problem displayed on the screen is a line of monochrome medals that represents the total number of correct solution patterns. When the learner discovers a

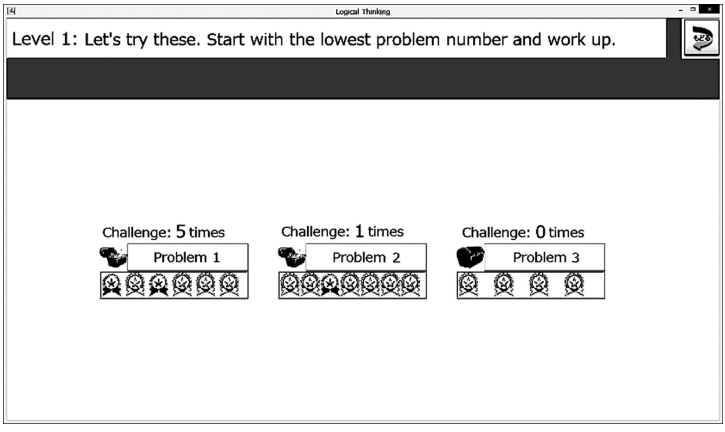

Fig. 2. Problem selection screen

correct pattern, the medal corresponding to that pattern is displayed in color to indicate the achievement.

When the learner clicks a button to select a problem, the display changes to the exercise screen (Fig. 3). A four-frame comic strip is presented on the right side of the screen and the cards to be used in constructing the logic are arranged on the left side.

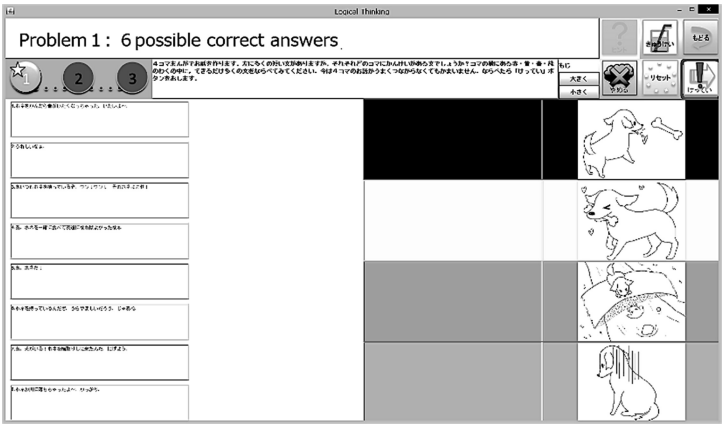

Fig. 3. Exercise screen 1

The number of cards depends on the problem, but varies in the range from 8 to 10. On each card, a short sentence of one of the types listed below is written.

(a) A part of a series of explanations and dialogs that are logically consistent with the fourth frame of the four-frame comic strip
(b) Explanations and dialogs that are logically consistent with a part the four-frame comic strip
(c) Explanations and dialogs that are similar to the cards that of types (a) or (b) and can easily be mistaken

By collecting and arranging the cards of type (a) and (b), it is possible to represent all of the logical development patterns that are obtainable for the problem four-frame comic strip. From four to nine patterns are possible, depending on the problem.

The learner can drag and drop the cards to line them up beside each frame according to their interpretation. When done, the learner can click the 'Done' button in the button group in the upper right of the screen to line the selected cards up horizontally beside each frame (Fig. 4). The learner then considers the logical development of the four-frame comic strip and selects the frames and arranges the cards horizontally beside each frame accordingly. When the learner clicks the 'Done' button, the system returns feedback on whether the result is correct or not. If it is correct, the learner can try to build another logic structure; if it is incorrect, the learner can either try again to build the logic or try to build a different logic. When the learner feels that enough has been done for one comic strip, they can move on to a different problem.

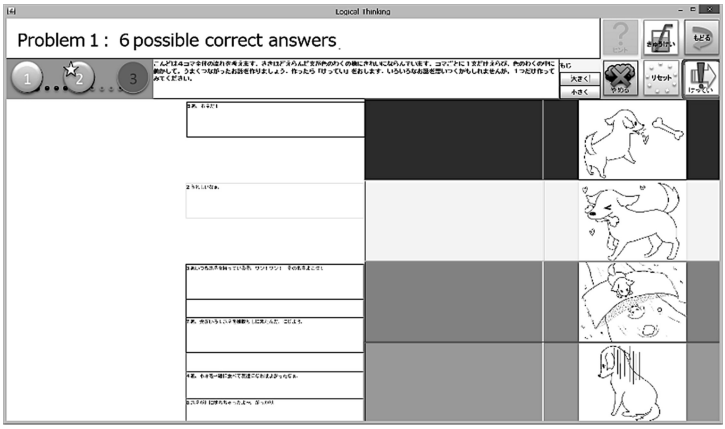

Fig. 4. Exercise screen 2

4 Experiment

4.1 Purpose

This experiment is intended to test whether or not the system described here can implement the open-ended, interactive exercises for four-frame comic that are the objective of our research. Although we have argued for the importance of these exercises, they cannot be implemented manually. Accordingly, the design and development of a system for implementing them is essential to an empirical demonstration of significance. Here, we show experimentally that it is possible to implement a system that handles these exercises. The kind of exercises and system described here have not previously been proposed or implemented, so confirmation of their feasibility would be a highly novel result.

4.2 Subjects

The subjects were 24 elementary school students (ten 4th graders, ten 5th graders, and four 6th graders) in the Personal Computer Department of a public elementary school. The subjects are accustomed to using personal computers.

4.3 Procedure

(a) Explain the system and exercise method. (2 min)
(b) Pretest: Present a four-frame comic strip (Fig. 5) and instruct the learner to describe a coherent story and create stories as many different logical patterns as possible. (15 min)
(c) Use the system to do an exercise: log in and solve problem 1. (7 min)
(d) Check the problem solving method by using Problem 1 as an example. (3 min)

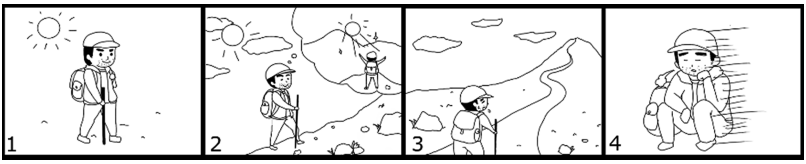

Fig. 5. Four-frame comic strip used for the pretest

(e) Use the system to do exercises: Instruct the learner to first construct one logical pattern for each of the remaining six problems, and then construct at least two stories (logical developments) for any problems they like. (23 min)
(f) Post-experiment questionnaire (5 min)

The time from log-in to log-out is 33 min. Of that time, 3 min are used to check the method for solving the problems and 30 min are for using the system to do the exercises.

4.4 Evaluation

(a) Pretest: Investigate what kinds of stories the subjects can create with the description formula and what level of description is possible.
(b) Questionnaire: Ask about the subjects feelings regarding the exercises, such as if the exercises were fun, if the problems were difficult, and if they would like to do them again.
(c) Learning log: The pages viewed by the subjects, the buttons clicked, the logic patterns constructed, and the times at which each behavior occurred, etc. are all recorded in a log.

5 Results and Discussion

When the pretest ended, nearly all of the subjects had finished writing, so the time for the pretest was sufficient for the subjects to write down all of the stories they could think of. However, there was often insufficient explanation of the four-frame comic strips for which the subjects wrote, so there were not many for which the logical development could be understood. For that reason, if an explanation for four frames was written in the form of a story, it was regarded as one story.

When using the system, on the other hand, the time for constructing a variety of logical developments was entirely insufficient for all of the problems. Furthermore, because the subjects were instructed to first create one story for all of the problems in step 3 of the experiment, only one pattern was created for many of the problems. That phenomenon was seen particularly often for the level 2 problems (about 44 %). That is to say, many subjects concentrated on the exercises for level 1 problems. For that reason, we compared the number of medals earned (i.e., the number of logical developments) per problem in the exercises for level 1 problems 1, 2, and 3 with the

number of compositions in the pretest. The number of medals earned per problem for level 1 was 2.22 (SD = 1.42) and the average number of compositions in the pretest was 1.46 (SD = 0.83). A paired-sample difference test showed that the number of medals earned per problem in the level 1 exercises using this system, which is to say the number of logical development patterns, was significantly greater ($t(23) = 2.49$, $p < .05$). We can therefore conclude that the exercises done with this system enabled the subjects to construct more logical development patterns.

Next, investigation of the number of medals earned (number of logic patterns created) in exercises done using this system revealed that the average per person was 11.91 (SD = 4.71). We can see that this result indicates the number of logical patterns that can be constructed. The average for 15 min number of patterns for describing the stories on paper in the pretest was only 1.46 (SD = 0.83), and only a few of those had a logical structure that could be read for comparison and study. Although the time taken doubled to 30 min when the system was used, the number of appropriate logical development patterns that could be constructed in that time increased by a factor of more than 8 and the patterns could be compared. Also, considering the number of possible combinations, we can say that it is not possible to create appropriate logical development patterns without logical thinking. These facts show that subjects who had difficulty constructing even a single logical structure on paper could build multiple logics for a single problem when using this system.

The average number of medals earned by students was 15.25 (SD = 1.89) for the 6th graders and 11.25 (SD = 4.84) for the 4th and 5th graders. A difference test for the two groups shows that the 6th graders earned significantly more medals ($t(19) = 2.77$, $p < .05$). That is to say, the 6th graders were more successful in constructing multiple logics from diverse points of view. According to Kishi, understanding of the logical structure of text is acquired between the 4th grade and the 6th grade, and 6th graders have reached nearly the level of university students for the ability to understand the important parts of logical structure [17]. This difference in development is probably reflected in the difference in our results.

Next, we consider the time taken to do the exercises with the system. To obtain the actual time taken for each exercise, we obtained the times for actually doing and viewing each exercise from the exercise logs and used the summed data. The actual exercise time excludes time for changing to irrelevant pages and long periods of inactivity of the system and includes only time spent interpreting the four-frame comics, considering the logical development, and moving the cards accordingly while the system is running.

The time spent and the number of subjects that did the exercises are presented in Table 1. The χ^2 test indicated significance in the results. The subjects that did the exercises in from 25 to 30 min were the largest group, and very few spent from 15 to 20 min on the exercises.

The total time in which the system could be used to do the exercises was 30 min. Although two subjects took from 30 to 35 to actually do the exercise, that is considered to be a result of the time for ‘checking the solution method using problem 1 as an example’ during the process and using the system up to the time for answering the post-experiment questionnaire. The largest group of subjects took from 25 to 30 min, which is to say they did exercises more or less straight through from beginning to end.

Table 1. Actual learning times for test subjects

Learning time (minutes)	Persons
30 to 35	3
25 to 30	12
20 to 25	7
15 to 20	2
χ^2 (3) = 10.33, p < .05	

Although some subjects took from 20 to 25 min, they are considered to have done the exercises as such. These facts indicate that the subjects participated fully in using the system to do the exercises.

A questionnaire was given to the subjects after the experiment to obtain subjective evaluation. Many subjects reported that the exercises were difficult (Table 2). On the other hand, significantly many subjects reported that the exercises were fun and that they would like to do more of the same kind of exercises (Tables 3 and 4). That is to say, the exercise could be enjoyed and there was motivation to do similar exercises despite the difficulty. These results show that the exercises can be by accepted learners.

Table 2. Evaluation of difficulty

Question item	Persons	Significance
This exercise was difficult	19	p < . 01
This exercise was not difficult	5	

Table 3. Evaluation of enjoyment

Question item	Persons	Significance
This exercise was fun	23	p < .01
This exercise was not fun	1	

Table 4. Evaluation of willingness to try again

Question item	Persons	Significance
I would like to try this kind of exercise again	20	p < .01
I would not like to try this kind of exercise again	2	

6 Conclusion

We have proposed open-ended, interactive logic-building exercises based on four-frame comic strips and implemented them in a learning system. Experiments confirmed that learning is possible with this system. This method provides children with the experience of building multiple logical patterns from the same target material,

which has not previously been possible. This activity is relevant to fostering the capability and attitude of logical analysis from multiple perspectives, and we can expect it to promote education that develops the capacity for critical thinking that will be needed for living in our future society. We confirmed the feasibility of using this system for learning with the types of exercises described here. Further work on ways to incorporate this system into educational contexts and on measurement and analysis of the learning effect is needed.

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