

Experimental investigation of effects of representations and contexts on comprehension and generation line graphs

Nana Kanzaki (kanzaki@cog.human.nagoya-u.ac.jp)

Graduate School of Information Science, Nagoya University, Japan

Kazuhisa Miwa (miwa@is.nagoya-u.ac.jp)

Graduate School of Information Science, Nagoya University, Japan

Abstract

In this study, we investigated the representation effect in comprehending graphs. Many previous studies have confirmed the representation effect. In Experiment 1, we replicated the representation effect but using a set of graphs each of which is completely identical from the other in its perceptual characteristics. Participants drew a specific aspect of information from a line graph depending on the relation of x-axis and z-legend of the graph. In Experiment 2, participants were given a context for problem solving. The result showed that participants read a graph based on a given context; and the representation effect in comprehension was limited. In Experiment 3, participants generated a line graph by themselves. The result showed that they did not necessarily generate a consistent graph with a given context, and in comprehension the requirement of a context has very strong effects similarly as in Experiment 2.

Keywords: representation; context; graph comprehension; graph generation

Introduction

It is efficient to use diagrams for solving problems (Larkin & Simon, 1987). There are many previous studies about effects of graph representation and prior knowledge of the graph readers on graph comprehensions.

Effects of representations of graphs on graph comprehension

Graphs can be represented as various forms. Different representations of graphs generated from an identical data set elicit different interpretations of the graphs. We call this effect of representation on graph comprehension the representation effect.

The representation effect has been confirmed through various previous studies of graph comprehension. For example, in studies of inferences from bar and line graphs, viewers are more likely to describe x-y trends when viewing line graphs than bar graphs (Zacks & Tversky, 1999; Shah, Mayer, & Hegarty, 1999). By contrast, bar graphs emphasize discrete comparisons (Zacks & Tversky, 1999; Shah et al., 1999). Peebles and Cheng (2003) suggested that the comprehension time of certain information differs depending on the graph structure. Shah and Carpenter (1995) confirmed that x-y trends were comprehended easily, although z-y trends were comprehended with difficulty, using three-variable line graphs (e.g., Carpenter & Shah, 1998).

In the preceding studies, a set of two graphs was usually used. Two graphs were generated from an identical data set. The relation of x-axis and z-legend was reversed in one graph from the relation in the other graph. However, perceptual

shapes of the two graphs were different; therefore, the representation effect identified and the effects of such perceptual shapes were confounded. One important improvement of an experimental approach in the current study is that we use a set of graphs each of which is completely identical from the other in its perceptual characteristics.

Effects of contexts on graph comprehension

Graphs are used in various situations and often utilized to solve specific problems. When graphs are used in a certain context, their comprehension might be affected not only by their representations but also the given contexts and perspectives determined by the contexts. We examine the effect of such contexts on the comprehension of information from graphs.

Freedman and Shah (2002) proposed a model of graph comprehension using a framework provided by the Construction-Integration (CI) model of text and discourse comprehension (Kintsch, 1988). In this model, the comprehension of graphs is influenced by the interaction between the bottom-up processes of visual features and the top-down processes of such prior knowledge as domain knowledge, graphical literacy skills, and explanatory skills. Shah and Hoeffner (2002) reported that the comprehension of graphs was difficult if the information in the graphs contradicted the viewers' prior knowledge. Moreover, Freedman and Smith (1996) observed that viewers tended to overestimate the trends of data when their prior knowledge of the domain was activated.

However, when viewers read graphs for a specific purpose, they sometimes have perspectives given by a certain context without expectations about the data tendency. In the previous studies of text learning, the effects of the given perspectives were confirmed (Pichert & Anderson, 1977; Schraw, Wade, & Kardash, 1993). If this idea can be expanded to graph comprehension, the representation effect might be affected by such given contexts. The second objective of this study is to investigate how the representation effect and given contexts interact on graph comprehension.

It has been noted that constructing, generating, and selecting graphs are important for graph comprehension skills (Friel, Curcio, & Bright, 2001). Graphs are often generated by viewers themselves in certain contexts. If the representation effect is affected by given contexts, one crucial question is: can undergraduates generate graphs whose representations are appropriate for the given contexts? The third objective of this study is to investigate whether or not undergraduates generate graphs consistent with the representation effect in

contexts in which the graphs are used.

Additionally, we also investigate the differences in comprehending graphs provided by others and generated by viewers themselves. The comprehension of graphs is presumably affected not only by their representations but also the activities that generated them when the graphs were generated by viewers themselves.

Cox (1997) confirmed qualitative differences in mistakes made by problem solvers between solving problems with provided diagrams and while generating diagrams. Furthermore in learning situations, more positive effects have been confirmed in learning while comparing their own generated diagrams and diagrams provided by others than in learning with only provided diagrams (Meter, Aleksic, Schwartz, & Garner, 2006). Therefore it is possible that there is a different tendency in graph comprehension when reading provided graphs and reading graphs generated by viewers themselves.

Experiment 1

Experiment 1 investigated whether the degree of ease of comprehending information in line graphs changes depending on their representations, even when the graphs generated from an identical data set, in other words, to confirm the representation effect pointed out in previous studies. In Experiment 1, the representation effect was investigated from the viewpoint of the comprehension of the simple main effects of line graphs.

Method

Participants Forty-two undergraduates participated in the experiment. Half was assigned to the original graph condition where they read an original graph described as follows, and the other half was assigned to the interchanged graph condition where they read an interchanged graph in which the independent variables of the x-axis and the z-legend of the original graph were interchanged.

Materials Figure 1 shows example graphs used in Experiment 1. The graphs consist of two independent and one dependent variables. For the effect on a dependent variable, there is an interaction of two independent variables. The shapes of the original graph and its interchanged graph are identical. Independent and dependent variables that do not correlate in a usual context were selected as the labels of factors so that participant comprehension may not be influenced by their prior knowledge.

Procedure The experiment was performed as part of the assignments in an information literacy class. The participants read the provided graph and described the information gleaned from it. Seven minutes were assigned for this task. An example of the instructions is as follows:

“The following graph shows the amount of books sold in a certain bookstore as a function of temperature and humidity. Based on this graph, describe how temperature and humidity influenced book sales.”

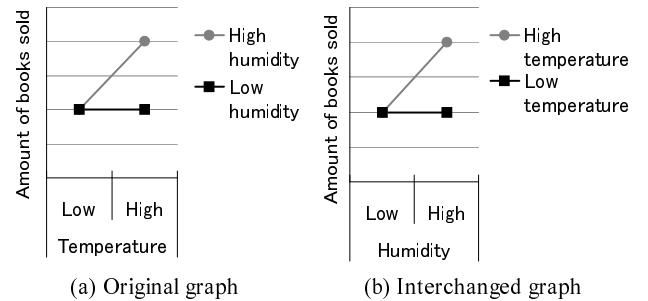


Figure 1: Examples of graphs used in Experiment 1. Figure 1(a) is an example original graph, and Figure 1(b) is its interchanged graph.

Classifying descriptions The participant descriptions were classified by the simple main effects described. The classification criteria were as follows:

(1) Descriptions about the simple main effect of a factor placed on the x-axis (*x-axis simple main effect* description); an example description in this category for a graph where the x-axis was temperature was as follows:

“When the humidity is high, sales increase as the temperature rises. But when the humidity is low, sales do not change even if the temperature changes.”

(2) Descriptions about the simple main effect of a factor placed on the z-legend (*z-legend simple main effect* description); an example description in this category for a graph where the x-axis was temperature was as follows:

“When the temperature is high, sales increase as the humidity rises. But when the temperature is low, sales do not change even if the humidity changes.”

Results and discussions

Figure 2 shows the proportions of participants whose descriptions were classified as the *x-axis* and *z-legend simple main effect* descriptions in each condition. The participants who described both *x-axis* and *z-legend simple main effects* were double-counted. In both the original and interchanged graph conditions, the proportion of the *x-axis simple main effect* descriptions was significantly larger than that of the *z-legend* descriptions (in the original graph condition: $p = .015$; in the interchanged graph condition: $p = .000$, one-tailed Fisher's exact tests).

These results indicate that the information comprehended from graphs changed when the x-axis and z-legend factors in the graphs were interchanged, confirming the representation effect. Therefore, these results suggest that the degree of ease of comprehending information depends on the graph representations even if the graphs are generated from the identical data set. In the following experiments, we investigate the factors that affect the degree of ease of comprehending information regarding the *x-axis simple main effect* description as information comprehended easily and the *z-legend simple main effect* description as information comprehended with difficulty.

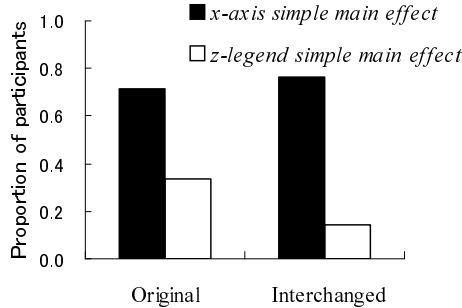


Figure 2: Proportions of participants whose descriptions classified as *x-axis* or *z-legend simple main effect* descriptions in Experiment 1.

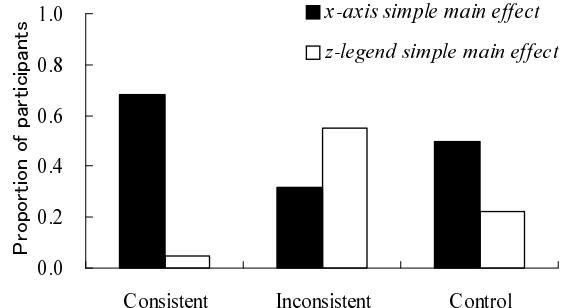


Figure 3: Proportions of participants whose descriptions classified as *x-axis* or *z-legend simple main effect* descriptions in Experiment 2.

Experiment 2

In Experiment 1, we investigated the representation effect when a graph was provided without specific contexts. But generally, graphs are read in a specific problem-solving context. A specific problem-solving context may have graph readers to draw certain information from a graph. In Experiment 2, we investigated how the representation effect and given contexts interact in graph comprehension.

In Experiment 2, the participants read graphs in specific contexts. The shape of the graph used in Experiment 2 was identical to the one used in Experiment 1. The labels of the dependent variables were “amount of imports” (large/small) and “amount of exports” (large/small), and the label of the independent variable was “net income.”

One of two contexts was given to the participants: (1) *import adjustment*: a context was given in which net income must be increased by adjusting the amount of imports, and (2) *export adjustment*: a context was given in which net income must be increased by adjusting the amount of exports.

It is presumed that the *import adjustment* context facilitates comprehending that the amount of imports should be increased (or kept) when the amount of exports is large (or small). Therefore, this context facilitates the comprehension of the simple main effect of the amount of imports. On the other hand, it is presumed that the *export adjustment* context facilitates the comprehension of the simple main effect of the amount of exports.

Method

Participants Fifty-nine undergraduates participated in the experiment for which three conditions were set up: (a) consistent condition: the participants read a graph in which the information required to be drawn by a given context was comprehended easily, (b) inconsistent condition: the participants read a graph in which the information required to be drawn by a given context was comprehended with difficulty, and (c) control condition: the participants read a graph without contexts. The participants were randomly arranged into one of the three conditions. There were 19 participants in the consistent condition, 22 in the inconsistent condition, and 18 in the control condition.

Tasks The graph was the *x-axis import* graph or the *x-axis export* graph, both of which were identical to the graphs generated in Experiment 2. In each experiment condition, the participants were given a context by instructions printed on an experiment sheet. Half of the participants in each condition was given the *import adjustment* context, and the other half was given the *export adjustment* context.

In the consistent condition, half of the participants was given the instructions of the *import adjustment* context and presented with the *x-axis import* graph. The other half was given the instructions of the *export adjustment* context and presented with the *x-axis export* graph. By contrast, in the inconsistent condition, half of the participants was given the instructions of the *import adjustment* context and presented with the *x-axis export* graph. The other half was given the instructions of the *export adjustment* context and presented with the *x-axis import* graph.

In the control condition, the participants received no contexts, and half was presented with the *x-axis import* graph, and the other half was presented with the *x-axis export* graph.

All participants described what influence the amount of imports and exports had on net income based on the presented graph.

Coding description The participant descriptions were classified with the same criterion as in Experiment 1.

Results and discussions

Figure 3 shows the proportions of participants whose descriptions were classified as *x-axis* or *z-legend simple main effect* descriptions in each condition. First, the same Fisher’s exact test as in Experiment 1 was performed in the control condition. The proportion of *x-axis simple main effect* descriptions was marginally larger than that of the *z-legend* descriptions ($p = .082$). This result is consistent with the result in Experiment 1.

Second, to examine whether a given context influences the degree of ease of comprehending information, paired comparisons were performed between the control condition and each of the two experimental conditions. In the consistent condition, a two (conditions: consistent and control) x two (descriptions: *x-axis* and *z-legend simple main effects*) test of two

factors' interaction in proportions using the z-scores was performed. There was a marginal interaction ($z = 1.62, p < .10$).

Next, in the inconsistent condition, a two (conditions: inconsistent and control) x two (descriptions: *x-axis* and *z-legend simple main effects*) test of two factors' interaction in proportions using the z-scores was performed. There was a significant interaction between the two factors ($z = 2.26, p < .05$). Subsequently, Fisher's exact tests (one-tailed) were performed in each description. The proportion of participants describing the *z-legend simple main effect* in the inconsistent condition was significantly larger than in the control condition ($p = .039$). But there was no difference between the two groups in the *x-axis simple main effect* descriptions ($p = .200$).

These results indicate that the information comprehended with difficulty can be relatively easily inferred from graphs when contexts that promote inference of the information are given. This means that the representation effect confirmed in Experiment 1 is limited when specific contexts require participants to read certain aspects of information.

Experiment 3

In Experiments 1 and 2, the effects of representation of graphs and given contexts in graph comprehension were investigated. Furthermore, we performed Experiment 3 to investigate how the representation effect and such given contexts interact in generating a graph.

In Experiment 3, the participants were given identical contexts as in Experiment 2 and generated graphs from provided data. The results of Experiments 1 and 2 imply that the participants are expected to generate a consistent graph where the representation effect and given contexts do not contradict. Additionally, we also replicate the findings confirmed in Experiments 1 and 2 when interpreting graphs generated by viewers themselves.

Method

Participants Eighty-five undergraduates participated in the experiment and were randomly assigned to one of the three conditions: (a) *import adjustment*, (b) *export adjustment*, and (c) control. There were 28 participants in each of the *import adjustment* and control conditions and 29 in the *export adjustment* condition.

Tasks There were two tasks in Experiment 2.

Task 1: graph generation task: the participants were given a set of data to calculate the mean value of the net income in each of four situations: large or small amount of imports and large or small amount of exports. Based on their calculated results, the participants drew graphs on experiment sheets shown in Figure 4. The participants selected the labels of the x-axis and the z-legend by themselves. The instructions for the *import adjustment* condition were as follows:

“The data show the relationship between the net income and the amount of imports and exports in a certain company that cannot determine the amount of exports because of a contract with their destination. The amount

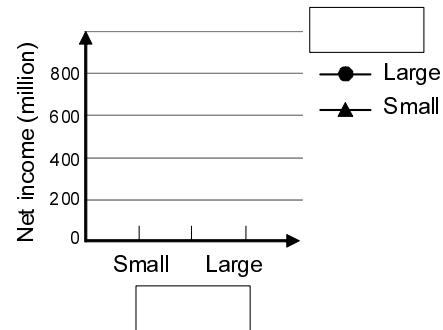


Figure 4: Graph format used in Task 1 of Experiment 3.

of exports changes randomly. On the other hand, they can adjust the amount of imports. You have to explain how to adjust the amount of imports based on the change of the amount of exports to improve net income.”

In the instructions for the *export adjustment* condition, “destination” for exports was replaced with “supplier” for imports and “imports” and “exports” were interchanged.

In the control condition, the following instructions were printed without contexts.

“The data show the relationship between the net income and the amount of imports and exports in a certain company.”

Task 2: reading graph task: the participants read a graph generated by themselves in Task 1 and were provided with the following instructions: “Based on this graph, describe the influence of the amount of imports and exports on net income.”

Classifying generated graphs The generated graphs in which the amount of imports was placed on the x-axis and the amount of exports was placed on the z-legend were classified as *x-axis import* graphs. On the other hand, the graphs in which the amount of exports was placed on the x-axis and the amount of imports was placed on the z-legend were classified as *x-axis export* graphs.

Classifying descriptions The participant descriptions were classified by almost the same criterion as in Experiment 1. For the *x-axis import* graphs, descriptions about the simple main effect of the amount of imports were classified as *x-axis simple main effect* descriptions, and the simple main effects of the amount of exports were classified as *z-legend simple main effect* descriptions. By contrast, for the *x-axis export* graphs, descriptions about the simple main effect of the amount of exports were classified as *x-axis simple main effect* descriptions, and the simple main effects of the amount of imports were classified as *z-legend simple main effect* descriptions.

Results and discussions

Generated graphs Nine participants were excluded from analysis because they generated incorrect graphs. Table 1 shows the numbers of graphs classified into each category in each condition. First, to examine the distribution of the

Table 1: Numbers of participants who generated *x-axis import* or *x-axis export* graphs in Experiment 3.

	<i>x-axis import</i>	<i>x-axis export</i>
<i>Import adjustment</i>	13	13
<i>Export adjustment</i>	12	14
Control	14	10

graphs generated without contexts, Fisher's exact test (two-tailed) was performed on the distribution of the numbers of *x-axis import* graphs and *x-axis export* graphs in the control condition. There was no significant difference ($p = .541, n.s.$).

Second, to examine whether the structure of the generated graphs was influenced by the contexts, a three (conditions: *import adjustment*, *export adjustment*, and control) x two (generated graphs: *x-axis import* and *x-axis export*) chi-square test was performed on the distribution of the numbers of generated graphs. There was no significant difference in the distribution ($\chi^2(2) = 0.768, n.s.$). This result suggests that there was no difference in the structure of the generated graphs even when different contexts were given, implying that the participants did not necessarily generate graphs whose structures were consistent with the given contexts.

Next, we performed the same analysis as in Experiment 2. To do so, the participants were grouped depending on whether they generated a consistent graph with the given context or not.

Consistent graph generated group : the participants who generated a consistent graph with the given context: i.e., in the *import adjustment* condition, participants who generated *x-axis import* graphs, and in the *export adjustment* condition, participants who generated *x-axis export* graphs.

Inconsistent graph generated group : the participants who generate an inconsistent graph with the given context: i.e., in the *import adjustment* condition, participants who generated *x-axis export* graphs, and in the *export adjustment* condition, participants who generated *x-axis import* graphs. This means that in these graphs, the contexts encourage the participants to read information comprehended with difficulty, i.e., the *z-legend simple main effect* descriptions.

Comprehension of simple main effects Figure 5 shows the proportions of participants whose descriptions were classified as *x-axis* or *z-legend simple main effect* descriptions in each group. First, the same Fisher's exact test as Experiment 1 was performed in the control condition. The proportion of *x-axis simple main effect* descriptions was significantly larger than that of the *z-legend* descriptions ($p = .003$). This result was consistent with the result in Experiment 1.

Second, to examine whether a given context influences the degree of the ease of comprehending information, the same tests as in Experiment 2 were performed. The results showed no interaction in the comparison of the consistent and control groups ($z = 0.52, n.s.$), but a significant interaction in the comparison of the inconsistent and control groups

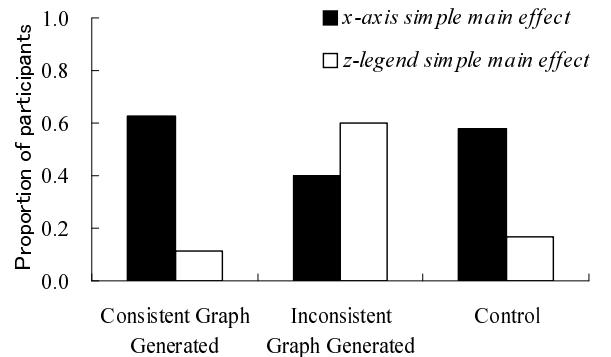


Figure 5: Proportions of participants whose descriptions classified as *x-axis* or *z-legend simple main effect* descriptions in Experiment 3.

($z = 2.93, p < .01$). Subsequently, Fisher's exact tests (one-tailed) were performed in each description. The proportion of participants describing the *z-legend simple main effect* in the inconsistent graph generated group was significantly larger than in the control group ($p = .008$). But there was no difference in the *x-axis simple main effect* descriptions between the two groups ($p = .159$).

These results indicate that information comprehended with difficulty can be inferred from graphs generated just like from graphs provided by others when contexts that promote inference of the information are given.

General Discussions

In this study, we investigated the representation effect using a set of graphs each of which is completely identical from the other in its perceptual characteristics. We confirmed that the changes of representations actually affected the comprehension of certain information drawn from graphs.

This result consists with multiple previous studies (Shah & Carpenter, 1995; Shah et al., 1999). Shah et al. (1999) concluded that graph comprehensions are affected by visual chunks. Their study suggested that the simple main effects of the x-axis are comprehended easier than the effects of legends because viewers make visual chunks of each line automatically and the cognitive loads for the comprehension of the simple main effects of the x-axis become lighter than for the comprehension of the legends.

In the CI model of graph comprehension (Freedman & Shah, 2002), graph comprehensions are made through the interaction between actual data and prior knowledge. Freedman and Smith (1996) confirmed that viewer perceptions depend on their prior theories activated beforehand. Prior knowledge dealt with in such previous studies provided viewers with specific expectations for the interpretation of data.

On the other hand, the contexts investigated in this study did not have viewers expect specific data tendencies, even though they required a certain perspective to comprehend the information. This result supports the idea that contexts for problem solving also affect the comprehension of graphs, as prior knowledge does.

In the results of Experiment 2, the effects of given contexts were much larger than the representation effect. In a previous study about the effects of given perspectives on text comprehension (Schraw et al., 1993), it was confirmed that the effects of the task-based importance (given perspective) on text learning were larger than that of the text-based importance determined by the text contents. So, the results of present study replicated this effect in graph comprehension.

In Experiment 3, the participants generated graphs in contexts that required the comprehension of certain information, but their graphs did not necessarily represent forms promoting comprehension of the information. It has been noted that constructing, generating, and selecting graphs are important for graph comprehension skills (Friel et al., 2001); however, half of them generated an inconsistent graph with the given context.

On the other hand, when contexts were given, the information promoted to be drawn by the contexts was more actively comprehended, even when inconsistent graphs were generated.

Since several previous studies focused on the effect of generating diagrams, we performed further analysis across Experiments 2 and 3. In the control condition of Experiments 2 and 3, a two (experiment: Experiments 2 and 3) x two (descriptions: *x-axis* and *z-legend simple main effects*) test of two factors' interaction in proportions using the z-scores was performed. There was no interaction ($z = 0.62, n.s.$). Therefore, we confirmed that there was no difference between the comprehension from graphs generated by the viewers themselves and from graphs provided by others.

Stull and Mayer (2007) indicated that learning while generating diagrams is not necessarily promoted, compared with learning while viewing diagrams provided by others, because, in the former case, extraneous cognitive loads emerge when generating diagrams. Our study found no difference between the two situations because the participants preliminarily generated graphs and then read them; no extraneous processing emerged while comprehending the graphs.

On the other hand, Meter et al. (2006) reported more positive effects in learning with graphs generated from texts while comparing the generated graphs with graphs provided from others than learning only with the provided graphs. They believe that this effect is caused by constructing mental models while generating diagrams and by elaborating such mental models while comparing generated diagrams with ones provided by others. However, in our study, this effect was not confirmed. The reason is because in our task generating diagrams did not require the elaboration of mental models of the relationship between the variables.

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