Effects of Scale Display Formats, The Number of Variables per Display and Use of Markers on Visualizing Line Graphs[1]

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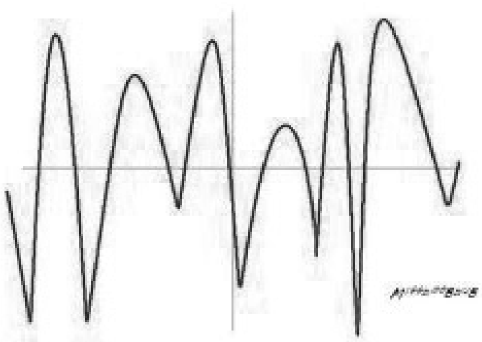
บทคัดย่อ

กราฟเส้นเป็นหนึ่งในเครื่องมือวิเคราะห์ข้อมูลที่ได้รับการยอมรับมากมาย เพื่อการตรวจสอบความสัมพันธ์ของตัวแปรเชิงปริมาณ แต่ทว่าการวิจัยในบริบทของประเทศไทยที่ได้สอบทานผลของรูปแบบสเกล จำนวนตัวแปรต่อกราฟ และการใช้จุดข้อมูลต่อความเข้าใจกราฟเส้นยังจำกัด การศึกษานี้จึงต้องการเติมเต็มส่วนที่ขาดหาย



การทดลองในห้องปฏิบัติการอันประกอบด้วยหน่วยทดลองที่เป็นนิสิตปริญญาตรีในหลักสูตรบริหารธุรกิจของประเทศไทยถูกสุ่มให้พิจารณากราฟแท่งที่นำเสนอเรื่องเดียวกันใน 12 ลักษณะ (รูปแบบสเกลสองรูปแบบ x จำนวนตัวแปรสามจำนวนต่อการแสดงหนึ่งรูปกราฟ x การใช้จุดข้อมูลสองลักษณะ) ผลการวิเคราะห์ข้อมูลพบว่า ผลของรูปแบบสเกลและจำนวนตัวแปรต่อกราฟต่อความเข้าใจกราฟเส้นมีนัยสำคัญทางสถิติที่ระดับ 0.05 แต่ผลของการใช้จุดข้อมูลหรืออิทธิพลร่วมของทั้งสามตัวแปรต่อความเข้าใจข้างต้นไม่มีนัยสำคัญ

นอกจากช่วยต่อยอดองค์ความรู้ของจินตทัศน์ทางธุรกิจในบริบทของผู้ใช้กราฟเส้นชาวไทยแล้ว ผู้พัฒนาซอฟต์แวร์ทางจินตทัศน์สามารถใช้ข้อค้นพบหรือปรับปรุงการนำเสนอกราฟที่เพิ่มความเข้าใจกราฟเส้นได้ด้วย

คำสำคัญ : รูปแบบสเกล จำนวนตัวแปรต่อกราฟ การใช้จุดข้อมูล ความเข้าใจกราฟเส้น ผู้ใช้กราฟชาวไทย

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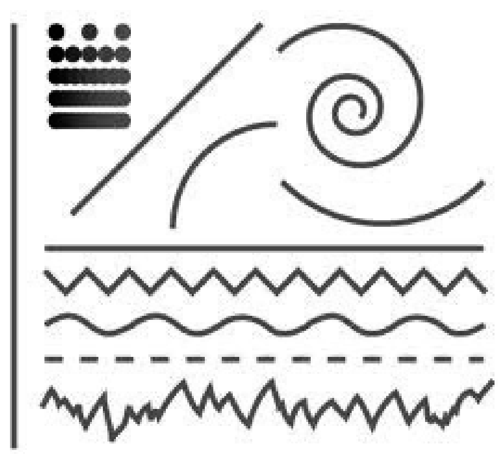
Abstract

One of the well-accepted data analysis tools in various fields, a line graph is often adopted to portray a relationship between variables. However, research in the Thai context examining effects of scale display formats (i.e., conventional or unconventional), the number of lines per display (i.e., one, three or six) and the use of marker (i.e., use or no use) on line graph visualization is rare. The current study intends to fill this gap.

A lab experiment in which 360 Thai undergraduates in one university's business school in Thailand were recruited to visualize 12 conditions of comparable line graphs (2 scale formats x 3 numbers of lines per display x 2 conditions of marker use) confirms that (1) the effects of scale display formats and the numbers of lines per display on visualization are statistically significant and (2) neither the effect of marker use nor the interaction effects of these three factors on the visualization is significant.

In addition to extending insight into issues of information visualization in the particular context of Thai line graph readers, graph developers could apply the study's findings to enhance readers' graph visualization.



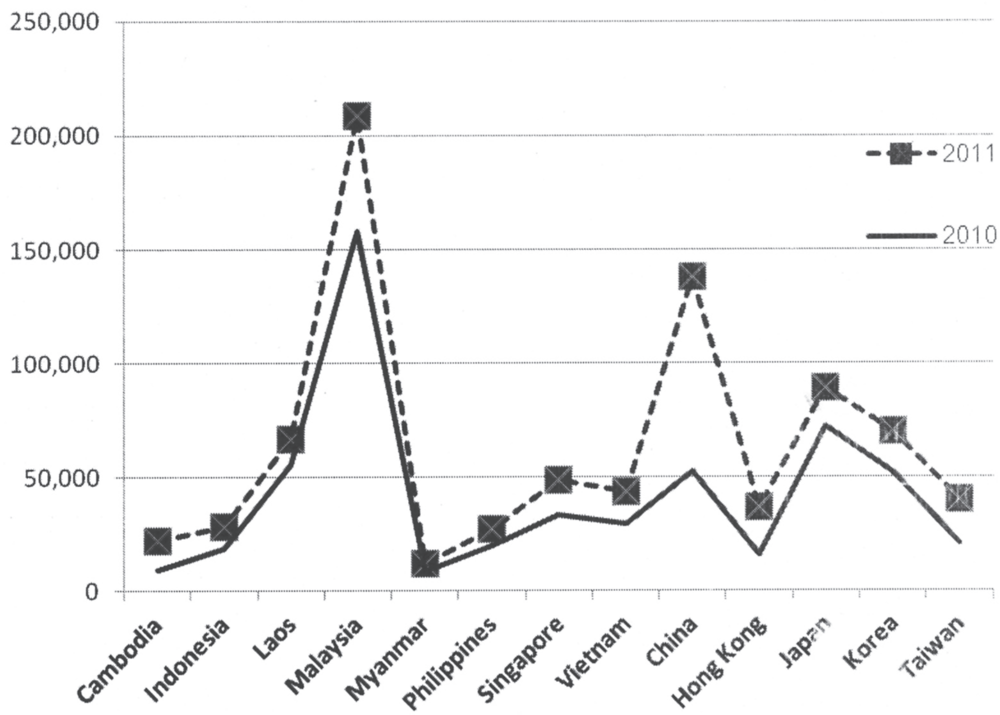
Keywords : scale display formats, the number of line graphs per display, use of marker, line graph visualization, Thai graph readers.

Problem Statement

A line graph is well known in numerous disciplines (Tan & Benbasat, 1993; Katz, 2008; Kosslyn, 2006; Kumar & Benbasat, 2004). The wide acceptance is a result of graph readers' capability in decoding quantitative data presented in the graph (Cleveland & McGill, 1985; Glazer, 2011). According to Kosslyn (2006), a line graph has three basic components: framework, content and label. First, the framework is of an "L-shaped" format (Kosslyn, 2006, p. 76). On the Y (vertical) axis are amounts (or frequencies) of what is measured. Commonly known as a dependent variable, it could be an currency exchange rate (measured in percentage) or temperature (measured in the Celsius unit). On the X axis are values of a variable in (1) at least an ordinal order such as ten years in one decade or (2) a few categories such as a group of countries. Second, the content is any symbol that exhibits a particular relationship between two variables identified in the framework. Such symbol in the current study is a line while in the others could be a bar or a dot. In Kosslyn's (2006) summary are recommendations on how to display content effectively. Finally, the labels are details supplementing the content. The details include names and units of Y or X axes, graph captions, graph titles, or background display. These labels may not be the graph's main focus but they often enhance its readability. Figure 1 illustrates one example of a line graph. The Y axis indicates the number of tourists visiting Thailand in 2010-2011 as noted by two lines. These visitors are from 13 countries as indicated on the X axis. The contents include two lines representing those numbers of tourists in 2010 and 2011. While the content in 2011 is in a dotted line with markers, that in 2010 is in a solid line with no marker. Also in Figure 1 are labels including the descriptions of the two axes and the legend.

According to scholars and practitioners in information visualization (Spence, 2007; Few, 2004; Kosslyn, 2006; Robbins, 2005), visualizing a line graph would be one's activity enabled through the use of computer-created representation of quantitative data. The activity is mainly to amplify one's cognition regarding the data representation. Spence (2007) claims that the advance in the field of information visualization is mainly due to three types of computational support. First, the more affordable access memory contributes to vast amounts of storage for all types of firms. Second, the highly powerful and quick computation "allows the rapid interactive selection of subsets of data for flexible exploration" (Spence, 2007, p. 16). This exploration is vital since one view of data representation may be too ambiguous to convey any meaning until individuals can examine the others. Finally, the state-of-the-art screens with high resolution and the direct manipulation interaction yields the perfect match between various human visualizing skills and multiple data representation formats.

Figure 1 Example of Line Graph and its Components



Based on the information visualization literature, the outcome of visualizing data encoded in a line graph is whether ones could correctly decode information in the chart (Cleveland & McGill, 1984; 1985; Lohse, 1993; Simkin & Hastie, 1987). So, our operational definition of visualizing a line graph is the extent to which viewers could respond correctly to questions regarding the data encoded in the graph. The correct responses are the graph viewers' proper interpretation of the data in the graph which could further indicate the success in presenting data in a line chart (Few, 2004).

Researchers have examined attributes of the line graph that could lead to proper visualization. Three attributes of our interest are scale display formats, the number of lines per display and use of markers. The scale display format refers to as a style of the scale presentation on a line graph used by a graph maker to convey different values of a given variable. The format could be of any value on X or Y axis. For example, the format used in Figure 1's Y axis is a numeric display of the number of tourists visiting Thailand. The importance of this scale display format is recognized in few papers, most of which are only conceptual remarks (Wilson & Addo 1994; Graham, 1937; Amer & Ravindran, 2010; Speier, 2006). Graham (1937), for example, identified six major factors that could affect graph visualization. Note that this classic work was far before computer technology becomes ubiquitous. The claim that various scale display formats could contribute to different levels of graph visualization is much noticed in the field of medical presentation. Schapiro and colleagues (2006) confirmed the effects of different formats of scale display on communication of breast cancer risk to patients. A few research projects have started to recognize the importance of scale display formats. Amer and Ravindran (2010) reported bias in making comparison as customers are seeking product information. The bias was affected by the scale display formats. Stone and coworkers (1997, 2003) have examined a set of variables that could affect a risk-related decision made after graph inspection. Speier (2006) confirmed that the scale display formats and decision performance were empirically moderated by the complexity of task.

Different formats of scale display on a graph include behaviorally-anchored rating scale (Benson, et, al. 1988), graphic display (Schapiro, et, al., 2006; Stone, et al., 1997, 2003), scale nearness as opposed to scale remoteness, scale coarseness as opposed to scale fairness (Graham, 1937). These findings may ascertain the critical applications of scale display formats to a graph, although only a few projects have addressed the scale display formats on a line graph. Typical graph makers may adopt a conventional display format so viewers could concentrate on interpreting a graph. Such conventional display could be the numeric value which may be a multiplication of 5 or an addition of 1,000 (e.g., in Figure 1, it is the addition of 50,000). Should graph makers adopt an unconventional format; however, this could add an interesting point to a line graph and challenge viewers to take a much careful look at it before decoding the meaning. Yet, no previous studies have examined such formats of display on a line graph. This current study intends to fill this gap.

The second attribute of our interest is the number of variables included in one display. Typically, one line will represent one variable in one graph display. Viewing only one line per display is such helpful that a viewer should be able to thoroughly detect a trend (Zacks & Tversky, 1997). However, numerous presentations have included many lines in one display to allow valid comparison. For instance, viewing a line graph that presents the amount of one country's rice export during 1991-2000 would likely lead to through understanding while viewing two lines that exhibit those of two countries' rice export during the same period would facilitate the comparison. Shah and Carpenter (1995) remarks; however, that too many lines in one display could require high cognitive load in order to decode the graph correctly. In fact, there are suggestions in which graph markers should not include too many lines in one chart (Kosslyn, 2006; Simkin & Hastie, 1987). Nonetheless, no paper have empirically examined the maximum number of lines per display. We thus attempt to empirically examine how many lines, between three choices of one, three and six lines, in one display that could lead to highest visualization. The selection of the three choices (i.e., one, three, or six lines) is arbitrary since we could locate only the remarks through which "do not include too many lines in one graph" was recommended. We hope our attempt should pave a way to more empirical studies on this issue.

The final attribute of our interest is the use of marker. Researchers have recommended that a line graph is a better choice than a bar graph if a graph maker wants to present a trend (Shah & Freedman, 2011; Zacks & Tversky, 1997; Kosslyn, 2006). In order to encode the graph content properly, a marker is often suggested when a few lines are in the same display. In many cases, a marker could distract graph viewing. It could be more serious when the graph framework is small. As a result, there is still a need to verify empirically if the use of marker in a line graph could yield a better visualization.

The Study'S Objectives

The previous review of conceptual work and empirical research strongly directs our attention to fulfill an important, yet largely overlooked, field of line graph visualization. Three main objectives are

1. Compare a line graph visualization between the graph with the conventional scale display format and that with the unconventional scale display formats

2. Compare a line graph visualization among the graph with 1, 3, and 6 lines in one display, and

3. Compare a line graph visualization between the graph with marker and that with no marker.

Research Methodology

Based on a lab experiment with a randomized complete block (RCB) design, we attempted to manipulate 12 displays of line graphs (2 scale display formats x 3 numbers of lines per display x 2 conditions of marker use) while controlling for other variables and then observe whether the graph visualization could be significantly different across values of the three factors. Should there be the statistically significant difference, it would empirically validate the effects of display styles on the line graph visualization. As a result, the study had to (1) select the content through which the 12 displays of the line graphs on computer screens could convey comparable meanings, (2) recruit experimental subjects to visualize the graphs and (3) perform comparison to validate the effects of these independent variables on the visualization.

Experimental Subjects

Not only do experimental subjects well represent the population of the study's interest, they must also be demographically compatible. With support from Chulalongkorn Business School, we were able to use their computer lab facilities.

Our experimental units were thus 360 undergraduates from Chulalongkorn Business School. Thirty of them were randomized to each of the 12 conditions of the experiment. The selection of these undergraduates is acceptable for their similar background; however, it imposes limited generalization of our findings.

Graph Content, and Manipulation of Independent Variables

The content on the 12 displays of line graphs must yield comparable meaning. This requirement is critical since the possible difference in visualizing the graph, if any, should result from the three display attributes. Given the Chulalongkorn Business School undergraduates as the experimental subjects, we strive to select the content of their interest. It is the figures of tourists visiting Thailand during 2001-2010 from six countries. Also, the language on the line graph is Thai since all subjects are Thai.

The line graph with no marker, one variable per display and unconventional format and the graph with marker, six variables in one display and conventional format are in Figure 2 and 3, respectively. On the graphs' Y axis are the numbers of the visitors to Thailand while the information on X axis indicates ten years (i.e., 2001-2010). Each year on the X axis in Figure 2 has one plot (or one coordinate) and each year on the same axis in Figure 3 has six plots, indicating the six countries from which the visitors are. While a addition of 5,000 as seen in Figure 3 represents the conventional scale display format, that of 4,999 as seen in Figure 2 is an instance of the unconventional format used in this study. Regarding the number of line graphs per display, we opted for one, three, and six graphs per display. While in Figure 2 is the case of one graph, in Figure 3 is that of six graphs. For the use of marker, we used a round shape as in Figure 3 but it is absent in Figure 2.

Measuring Graph Visualization

The line graph visualization was measured in this study as graph comprehension. That is, we developed twenty multiple-choice questions to which subjects were required to visualize the graphs in order to provide a possible answer. The order of the questions in these 12 conditions were in random but all subjects had to respond to all questions. We also set a time limit of 20 minutes within which the subject had to finish the 20 questions and earned one point for a correct answer or zero for an incorrect answer or an unanswered item. The possible maximum and minimum visualizing scores are thus 20 and 0 points, respectively.

Figure 2 Line Graph with No Marker, One Variable per Display and Unconventional Scale Display Format

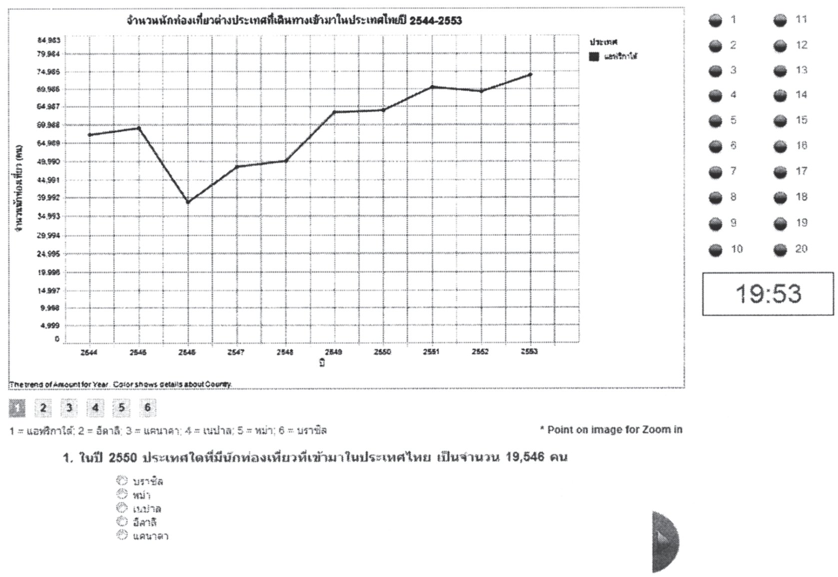
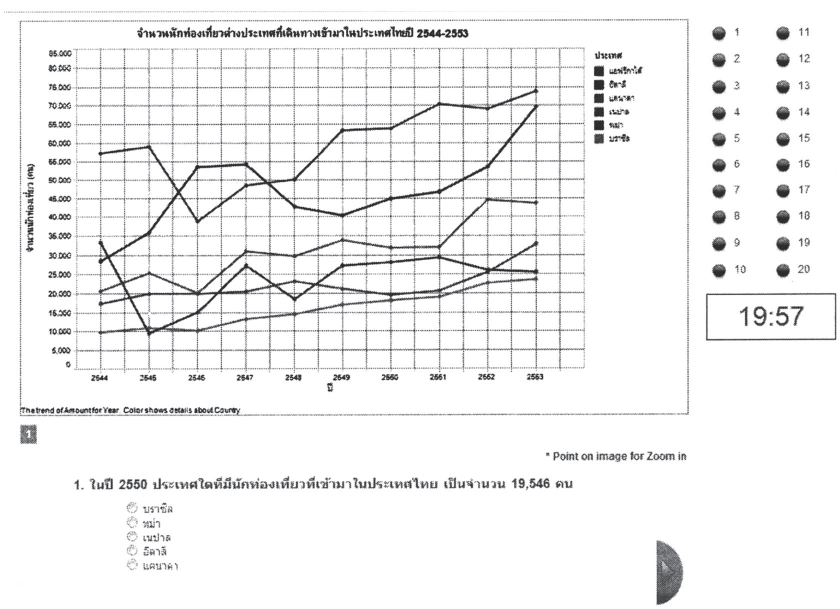


Figure 3 Line Graph with Marker, Six Variables per Display and Conventional Scale Display Format



Data Collection

360 undergraduates in Chulalongkorn Business School took part in the experiment that included three sessions using the school's computer labs. Some of the subjects received points for their participation. We tried our best to ensure the subject's technical compatibility in using computers. We randomized 30 subjects to one of the 12 experimental conditions. In each session, we intended to present adjacent students with different conditions so they were unable to copy the other's answer. Since we attempted to have the experiment that could replicate the actual working environment, we allowed the participant to use a calculator.

The participants were aware of the time limit of 20 minutes. All responses from the participants were recorded using the SQL database management system. The line graphs were prepared using Tableau and placed on a website so the participants would access through the Internet Explorer browser in the computer labs. To manage the display as well as to control the experiment sessions, we developed software using Visual Studio 2008, Microsoft server management studio 2005, ASP.Net and the IIS7 Internet Information Server.

Analysis Framework

We exported data from the database in the proper format for analysis using SPSS. The analysis has two folds. First, we presented key descriptive statistics of major variables. Second, we adopted the analysis of variance (ANOVA) technique to verify the three effects on line graph visualizing scores. To comply with the technique's basic assumptions, we intended to assess if the scores are normally distributed. If they are not, we seek to replace the ANOVA test with a nonparametric technique.

Results

Table 1 reports descriptive statistics of line graph visualizing scores, categorized by two scale display formats, three numbers of lines per display and two conditions of marker use. Based on this table, all 360 subjects received in average 12.46 points, the possible range of which are 0 and 20 points. It is therefore reasonable to state that the participating students' scores slightly above the midpoint, indicate their average performance in visualizing the line graph.

As seen in Table 1, the absolute values of skewness and kurtosis statistics are mostly in between -1 and 1. According to Mulylle and coworkers' (2004) recommendation, the visualizing scores in this experiment are normally distributed. Consequently, the comparisons of means of the visualizing scores across different values of all three independent variables are possible through the ANOVA test (Zikmund, 2003).

Table 1 Graph Visualization Scores: Descriptive Statistics

Variables	N	Mean	Standard Deviation	Skewness	Kurtosis
Scale display formats					
Conventional	180	12.80	3.22	-.858	1.085
Unconventional	180	12.13	2.83	-.399	.366
Numbers of lines per display					
One line graphs	120	11.55	2.92	-.491	.223
Three line graphs	120	12.47	3.44	-.700	.850
Six line graphs	120	13.37	2.43	-.359	-.296
Marker use					
Presence	180	12.63	3.02	-.671	.543
Absence	180	12.29	3.07	-.574	.872
Total	360	12.46	3.04	-.619	.676

The analysis results in Table 2 indicates that (1) effects of scale display formats and the numbers of lines per display on line graph visualization are statistically significant at a 0.05 level but (2) that of marker use or interaction effects of these three factors on the visualization are not significant. Given the statistically significant difference of visualizing scores among three numbers of line graphs per display, we further did multiple comparison using LSD. The results confirm that those who visualized six graphs in one display had statistically different performance than those who visualized one or three graphs in one display. Also, those visualizing three graphs in one display had statistically different performance than those who visualized one graph.

Based on the descriptive statistics in Table 1, the average of visualizing scores in the unconventional scale display format seems significantly lower than those in the conventional format. According to the results in Tables 1 and 2, the display of six line graphs hold the highest scores in graph visualization than the other two groups. Further discussion will be in the conclusion.

Table 2 Analysis of Variance Results

SOV	df	SS	MS	F	p-value
Scale display formats	1	40.67	40.67	4.65	.032
Numbers of lines per display	2	199.84	99.92	11.42	.000
Marker use	1	10.34	10.34	1.18	.278
Scale display format x Numbers of lines per display	2	5.61	2.80	.32	.726
Scale display format x Marker use	1	10.34	10.34	1.18	.278
Numbers of lines per display x Marker use	2	4.74	2.37	.27	.763
Scale display format x Numbers of lines per display x Marker use	2	4.24	2.12	.24	.785
Error	348	3045.77			
Total	359	3321.54			

Conclusion and Implications

We have examined whether the effects of (1) displaying six line graphs separately, in two sets of three lines or all together in one display, (2) using a marker and (3) using conventional or unconventional scale display formats on the graph visualization are statistically significant. The participants in the lab experiment were 360 undergraduates from Chulalongkorn Business School.

The average visualizing scores are 12.46 points, slightly above the half of the total of 20 points. Compared to the Thai student context (Tangmanee & Jittirat; 2012), the possible interpretation could be (1) the subjects in this study had slightly better visualization than those in Tangmanee and Jittirat (2012) or (2) the line graph is a better tool than the bar graph since it could lead to higher visualizing scores. Given no other publications in the Thai student context except the work of Tangmanee and Jittirat (2012), it is premature to draw any valid conclusion. It further indicates an urgent need to examine graph visualization in a specific context.

The comparison of visualizing scores between those reading line graph with conventional, and those reading the similar graph with unconventional, scale display formats confirmed that the difference is statistically different. Yet, the scores in Table 1 appear to point out that those who read it with the conventional scale format could achieve a higher level of visualization than those who read it with unconventional format. The plausible explanation is that encountering an unconventional (or odd) scale on a line graph could be much distracting and difficult for a viewer to correctly decode the graph. This finding is however in the opposite of that in Tangmanee and Jittirat (2012) in which visualization on a bar graph with an unconventional display format is better than that with a conventional format. Such contradicting results are very interesting since it opens for more research to systematically examine what leads to high graph visualization, especially in the Thai environment.

The significant effect of the number of line graphs per display on visualization warrants further discussion. It is evident that the more lines per display, the better visualization. Such finding is not what we had expected. However, once we took a closer look at our 20 problems for which our subjects had to visualize the line graphs to come up with the answer, most of the questions required comparison among information encoded in the graphs. Our findings are thus consistent. Had the problems demanded subjects to consider a trend of information presented in a line graph, about one or two lines would have been effective for trend detection (Kosslyn, 2006).

The trivial effect of marker use on visualization is of our surprise. This is because of the high number of recommendations in which a graph maker should add a marker to emphasize a data point on the line graph (Shah & Carpenter, 1995; Zacks & Tversky, 1997). The only possible explanation was that the size of the marker in our experiment might be less visible. Because of the trivial effect, we strived to look for a recommendation on the marker size. The surprise becomes much greater when we located no suggestion. To verify our speculation about the less visible marker, we asked a few undergraduates about the marker in this study. Many of them did not even notice the marker on the line graphs. This would therefore explain the possible cause of the trivial effect and further challenge other researchers to examine which size of the marker could enhance the line graph visualization.

The findings in which interaction effects of all three factors on line graph visualization are not significant call for further discussion. We could not locate any publication examining such interaction effects. Our discussion would thus be speculative. It appears that (1) although the scale display formats and the number of line graphs per display have statistically significant effects on visualization but the their interaction effect may cancel each other out and then become insignificant and (2) any interaction involving the use of marker seems trivial. These speculations should prompt a need for more empirical research on the interaction issue.

This study's results offer two major contributions. First is the theoretical contribution. The results have extended insight into effects of scale display formats and the number of lines per display on line graph visualization in the context of Thai student graph viewers. Second is a practical contribution. Graph designers should be attentive to how many line graphs they want to present in one display, since the number of them may deteriorate the graph visualization. The other practical utility is that the designers should be careful on the use of scale display formats. The conventional format in this study has proved to be statistically better than the unconventional one in improving the graph visualization.

The contribution could have been more visible, had this study not had two limitations. First, the experiment was done among Thai line graph viewers. The generalization to other contexts such as viewers of other nationalities or other types of graph seems inappropriate. Second, the lab experiment, albeit high in internal validity (Babbie, 2010), could offer little on issues of external validity. Consequently, there is research opportunity on these issues including an experiment in an actual setting where multiple graphs are used by various viewers.

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