Pre-Service Science Teachers' Interpretations Of Graphs: A Cross-Sectional Study

Abstract

This study focuses on pre-service science teachers' interpretations of graphs. First, the paper presents data about the freshman and senior pre-service teachers' interpretations of graphs. Then it discusses the effects of pre-service science teacher training program on student teachers' interpretations of graphs. The participants in the study were 117 pre-service science teachers. Fifty-six of the participants were freshman. The data of the study were gathered with a questionnaire adapted from Aoyama (2007). The questionnaire includes two graphs each based on a different context, and having four questions about the interpretation of the graphs. The participants' interpretations of graphs were analysed in five levels. The levels were listed from low to high level: Idiosyncratic, Basic Graph Reading, Rational/Literal, Critical, and Hypothesising and Modelling. The results of this study reveal that pre-service science teacher can read values and trends in graphs, but they are not successful at the higher levels within the interpretations of graphs hierarchy. Moreover, the Turkish pre-service science teacher training program does not promote student teachers' interpretations of graphs. These findings suggest that teaching modules should be designed to promote pre-service science teachers' interpretations of graphs and challenge them to go beyond basic graph reading. Furthermore, the factors that affect the pre-service science teachers' interpretations of graphs, such as the type of graphs and the context of the graphs, can be useful as the findings of the study can be used to aid in designing graphs teaching modules.

Keywords: Graphs, interpretations of graphs, teacher education, science education, cross-sectional study.

Introduction

In the 21st century, we frequently use graphs in our daily lives while reading newspapers, magazines, articles, watching TV news, and surfing on the net. Economic developments, election results, the results of public reports in the fields of education and health and so on are presented by graphs. Therefore, graphing competence is important and crucial for all the citizens who often need it in their daily life outside of the school environment. Graphs are used in many scientific disciplines (e.g., geography, economy, health, etc.) to analyse and organize the collected data (either qualitative or quantitative) and present them in a visual format (Batanero, Arteaga, & Ruiz, 2009; Shah & Hooeffner, 2002). Graphs serve many purposes. First, graphs present complex data concisely and precisely (Alacacı, Lewis, O'Brien, & Jiang, 2011; Bowen & Roth, 2005; Monteiro & Ainley, 2004). After the data are processed and put into graphs, the correlation and co-variation between the variables can be interpreted more easily (Bowen & Roth, 2005; Connery, 2007; Glazer, 2011; Vekiri, 2002). In addition, graphs help to determine the meaning of the data and help in making deductions and decisions (Doig & Groves, 1999; Bowen & Roth; 2002; Vekiri, 2002; Roth & Bowen, 2003). In this respect, graphing competence is not an easy task as it requires high-level cognitive abilities (Bowen & Roth, 2002; Bowen & Roth, 2005; Glazer, 2011; Grueber, 2011; Sharma, 2006).

Graphing competence includes both graph construction and graph interpretation skills (Aoyama, 2007; Glazer, 2011). Graph construction is the procedure of data processing (National Ministry of Education [NME], 2005; Monteiro & Ainley, 2003; Temiz & Tan, 2009). Technological advancements have both increased the graph variety (Vekiri, 2002) and contributed to the graph construction (Amer & Ravindran, 2010). For example, it has become easy for the individuals to enter only their data to form a graph with some computer programmes. There are even laboratory environments that save the data and convert the data into graphs automatically. So, technologic developments have reduced the skills that individuals are required to have for graph construction. However, the individuals still have the main role for the interpretation of the graphs (Glazer, 2011).

Graph interpretations refer to a graph reader's skill in obtaining meaning from graphs created by others or by themselves (Aoyama, 2007; Glazer, 2011; Temiz & Tan, 2009). Curcio (1987), who has made important contributions to graph interpretations competence, identified three levels in learners' interpretations of graphs. The first level is to read the values in the graphs directly. In other words, it means looking for explicit information presented in the values. The second level includes the calculation of the intermediate values, and understanding of the relation and trends between the values presented in the graphs. In this stage, comparisons are made between the values presented in the graph (bigger, smaller, the most, the longest, etc) and four operations are performed on the values (addition, subtraction, multiplication and division). In the highest level of reading beyond the values, the answers for complex questions can be found by interpreting the values in the graph. In this stage, the person who interprets the graph is asked to infer, guess, and conclude. There are various hierarchies that show parallelism to Curcio's three levels in students' interpretations of graphs in the literature (e.g. National Council of Teachers of Mathematics [NCTM], 2000; Wainer 1992).

Curcio's classification does not include the evaluation or criticism of values in the graph (Monteiro & Ainley, 2004). However, today individuals are expected to determine whether the values presented to them are biased or not, evaluate the information presented critically, and form and express opinions and viewpoints (Gal, 2002; Organisation of Economic Cooperation and Development [OECD], 2004). Aoyama (2007) has suggested a hierarchy that covers these elements for interpretations of graphs. The levels in this hierarchy are like chain rings; each upper level includes the former. These levels and the abilities expected from the students are discussed below:

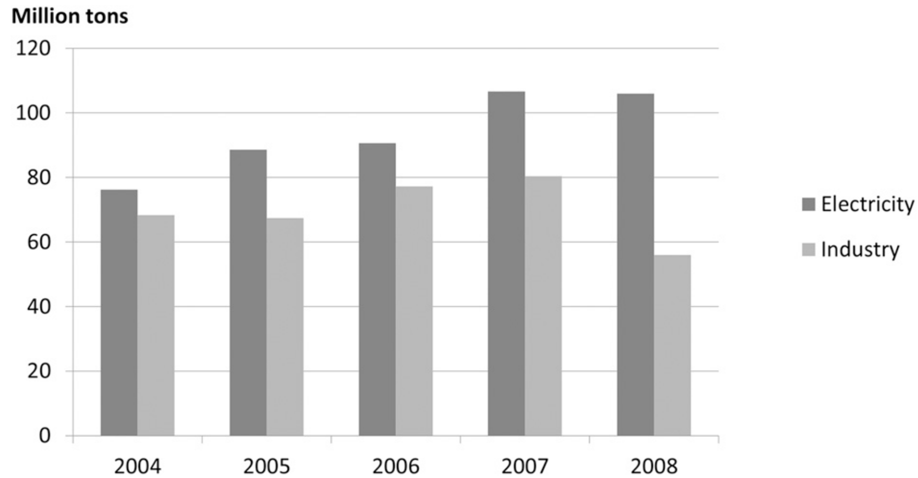

Figure 1. CO_2 **emission resulting from the fuel consumption according to the sectors (Turkish Statistical Annual, 2010)**

- *Idiosyncratic:* Students at this level read wrong values in graphs or avoid reading the graphs. For example, if students are given the graph in Figure 1 and are asked to determine how many million tons of industrial based CO_2 emissions were released in 2007, the anticipated answer is 80 million tons. If the student's answer is not 80 million tons or s/he does not answer the question at all then his/her interpretations of graphs are at the idiosyncratic level.
- *Basic Graph Reading:* Students can read the values and trends in the graphs. For example, if a student who analyses the graph in Figure 1 uses expressions such as, "industrial based CO_2 emission was 78 million tons in 2006" and /or "CO_2 emission based on electricity generation had been increasing from 2004 to 2008," s/he accomplish the task of basic graph reading.
- *Rational/Literal:* Students at this level read the values and trends in graphs correctly. They explain the contextual meaning of these values. For example, if a student can make a comment from the graph in Figure 1 such as, "One of the most important reasons for air pollution in Turkey is the electricity generation based on fossil fuels," his/her interpretations of graphs are at the rational/literal level.
- *Critical:* Students at this level can read the values in graphs correctly and understand the context of the data presented. Furthermore, they can assess the reliability of the contextual meaning defined in graphs. For example, a student who does not agree with the following hypothesis related to Figure 1 is exhibiting critical thinking: "Air pollution could be prevented if a filter were placed on the chimneys of all the industrial institutions in Turkey."
- *Hypothesising and Modelling:* Students at this level read graphs, and realize the trends. They know the contextual meaning of these tendencies. They can also criticize the information presented in graphs. Moreover, they can suggest explanatory hypotheses and models. For example, a student who does not agree with the hypothesis given in the critical thinking level and is able to suggest a logical, consistent, and alternative hypothesis related to the subject such as, "the renewable energy sources must be used more for electricity generation to reduce air pollution" shows interpretations of graphs at the highest level.

In fact, graphing competence can be taught in any course, e.g., history, business or culinary arts. However, interpretations of graphs as an important area of science education have been recognized in recent years because science is replete with data and graphs. Scientists obtain many data during their investigations and usually present the data in graphs or tables. They then make deductions and formulate explanations based on these graphs (Hoang, 2010).

Science curricula should be designed to help students to achieve science literacy everywhere in the world in the 21st century. A set of publications and standards such as *Benchmarks for science literacy* (American Association for the Advancement of Science [AAAS], 1993), the *National science education standards* (National Research Council [NRC], 1996), *Next Generation Science Standards* (Achieve, 2013) outline what students need to know, understand and be able to do to be scientifically literate at different grade levels. All of these benchmarks and standards recommend that a scientifically literate student should acquire graphing competence beginning in pre-school. By the end of the 12th grade, *Next Generation Science Standards* suggest that individuals who are scientifically literate should be able to use graphs to analyze and interpret data, acquire mathematical and computational thinking skills, engage in arguments from evidence and communicate effectively. In addition to curricula, assessment tools include references to graphing competence. For example, the Program for International Student Assessment carried out by OECD includes questions which require students to interpret graphs (Programme for International Student Assessment [PISA], 2006).

Although the importance of graphing competence is understood very well in an educational context, studies reveal that students do not always acquire graphing competence at an acceptable level (Demirci & Uyanık, 2009; Doig & Groves, 1999; Oruç & Akgün, 2010; Sharma, 2006; Temiz & Tan, 2009; Watson & Chick, 2004). Interpretations of graphs are not an easy task. Students often cannot learn to cope with this task on their own. If we want students to understand graphs, teachers are required to acquire the graph interpretation skills (Jocobbe & Horton, 2010; Szyjka, Mumba, & Wise, 2011). There are several studies intended to assess pre-service teachers' interpretations of graphs (e.g., Alacacı et al., 2011; Bowen & Roth, 2005; Jacobbe & Horton, 2010). Therefore, the study described in this paper focused on pre-service science teachers' interpretations of graphs. First, the paper reveals pre-service science teachers' interpretations of graphs. In addition, it compares the freshman and senior pre-service science teachers' interpretations of graphs. Thus, the findings of the current study provide an opportunity to discuss the effects of teacher training programs on student teachers' interpretations of graphs. The results of this study are important because interpretations of graphs have relevance to both instructors who teach pre-service science teachers and teachers who teach science for children.

Methodology of the Study

The developmental research method was used in the study. The purpose of developmental research is to assess changes over an extended period of time and is an ideal choice to assess the differences in academic or social development of students in various grade levels. The changes in the pre-service science teachers' interpretations of graphs throughout their teacher-training program were investigated in this study. Hence, this study was carried out with developmental research methods. The developmental research method can be undertaken using several designs: longitudinal, cross sectional and cross sequential. In this study researchers chose the cross sectional design because they compared freshman and senior pre-service science teachers' interpretations of graphs. Cross-sectional design involves looking at different groups of people of different ages who share the same experiences. The benefit of this type design is that it reduces the amount of time and the attrition rate in the developmental research (Çepni, 2010; Heffner, 2004; Hofer, Flaherty, & Hoffman, 2006).

Context of the Study

Pre-service science teachers in Turkey have to take a total of 61 courses during their four-year training. Pre-service science teachers take courses of general culture (i.e., Turkish language, computer, English, etc), science (i.e., physics, chemistry, biology, mathematics, biology laboratory, chemistry laboratory, physics laboratory, science education laboratory) and pedagogical knowledge (i.e., evaluation and assessment, teaching technologies and material design, education psychology, class management, teaching methods). Pre-service science teachers are engaged in graphs in physics, chemistry, biology, and mathematics courses in particular. Pre-service science teachers take these courses in the first three years of their teacher-training program. The study described here was carried out in a state university located on the Aegean coast of Turkey. The university has a history of 20 years. Undergraduate, graduate and postgraduate education is given in the Department of Science Teaching in Education Faculty.

Participants

The participants in the study were 117 pre-service science teachers. Demographically, 56 of the participants were freshmen in the teacher training program, with 38 of the freshmen being female. Sixty-one participants were senior students in teacher training program and 37 of them were females.

Instrument

The data of the study were obtained with a questionnaire adapted from Aoyama (2007). There are two graphs in the questionnaire. The first graph presents the findings of a research study of the number of hours elementary students play TV games per day and how many acts of violence they experience. In the next pages of this text we will call this graph *TV graph*. It is a bar graph. The second graph presents the literacy rate of forty randomly chosen countries and the gross national product per capita. It is a scatter plot. In the next pages of this text we will call this graph *literacy graph*. The graphs in the instrument are of different types and contexts. However, they both look like the graphs which frequently appear in visual and printed media. Each graph has four questions asking about interpretation of a graph. The first question of each graph asked the student teachers to read the value in the graph directly. We used the responses of the participants to these questions to decide whether their graphical interpretation was at the *idiosyncratic* level or above. The second questions concerning the graphs asked the student teachers to determine tendencies (provide interpretations) based on the data in the graphs. These questions test the *basic graph reading* level of the Aoyama's interpretations of graphs hierarchy. The third question asked about each graph required the participants to explain the data in the graph taking the context into account. These questions reveal whether the pre-service science teachers reach the *rational/literal* level of the interpretations of graphs hierarchy. The last questions asked about the graphs have two stages. In the first stage, a hypothesis based on data set in the graph was presented and participants were asked whether they agreed with this hypothesis or not. The decisions of the participants about this hypothesis reveal whether they are able to accomplish the skills needed to reach the *critical* level of the interpretations of graphs hierarchy. In the second stage, the participants were asked to explain the reasons for their responses in the first stage. The representative responses include a model/hypothesis. In other words, these questions assess whether the pre-service science teachers' interpretations of graphs are at the *hypothesising and modelling* level.

In order to provide the construct reliability of the instrument, the views of three experts were consulted. According to their feedback, necessary corrections were made. The questionnaire was piloted with a group of 30 pre-service science teachers. During the application, the participants were asked to underline the points they had difficulty in understanding. According to the information gathered from this application, the comprehensibility of data collection tool was determined. The graphs and their questions are included as Appendix 1.

Analysis of Data

The participants' interpretations of graphs were analysed under the *idiosyncratic*, *basic graph reading, rational/literal, critical, and hypothesising and modelling* categories. These categories are parallel with the interpretations of graphs hierarchy identified by Aoyama (2007). The data analysis started by coding the statements written in the questionnaire by the participants with respect to these five categories. If a participant did not answer a question of a graph, or wrote something irrelevant about the question, we used the *idiosyncratic* code for these responses. The statements of the pre-service science teachers for the TV graph in the questionnaire that indicated that 20.4% of the people who played TV games for an hour per day experienced violence "quite a lot" were coded as *basic graph reading*. If a student teacher stated that the more time allotted to playing TV games increased, the more the number of children's violence act experiences increased, this statement was coded under *rational/literal* category. The fourth question of the TV graph presents the following hypothesis to the participants: If the parents prevent the children from playing TV games, the problem of act of violence by the children can be solved. If pre-service science teachers stated that they did not agree with this hypothesis, this response was coded as critical. If a student teacher stated that the children who never played TV games could even experience the act of violence and/or mentioned other possible variables such as exposure to domestic violence which caused them to experience the act of violence in order to disagree with this hypothesis, this response was coded under *hypothesising and modelling* category. The authors of this study coded the data independently from each other. The inter-rater reliability was 95%. The few differences in coding were resolved by negotiation. After the process of coding data was completed, the frequencies and the percentages for the five different levels of the interpretations of graphs hierarchy were calculated. The freshman and senior pre-service science teachers' interpretations of graphs are presented in the Tables. These analyses were carried out for both the TV and the literacy graphs.

Results of Research

Table 1 presents the findings obtained from the interpretations of participants about the TV graph in the questionnaire.

Nearly 10% of the freshman and senior pre-service science teachers avoided reading the data in the TV graph directly or misread them. Nearly 90% of the participants could determine the tendencies in the TV graph. Nearly one fifth of both the freshman and senior pre-service science teachers could accomplish the skills of the rational/literal level of the interpretations of graphs hierarchy. Very few participants (16% of freshman and 28% of seniors) could criticize the suggested hypothesis depending on the data set in the TV graph. Only 10% of both the freshman and senior pre-service science teachers could suggest their own rational hypothesis/models by using the values in the TV graph.

Table 2 presents the participants interpretations of the literacy graph in the questionnaire.

Nearly 30% of pre-service science teachers could not read the values presented by the literacy graph. Nearly 70% of freshman pre-service science teachers and 65% of senior pre-service science teachers could interpret the literacy graph in the basic graph reading level. Less than 25% of the participants could interpret the literacy graph at rational/literal level. The participants who could interpret this graph at the critical level are quite few in number (freshman 32% and seniors 25%). There are scarcely any participants who could suggest their own hypotheses based on the values presented in the literacy graph.

Table 1. The distribution of graphical interpretation level for TV graph

	Idiosyncratic		Basic Graph Reading		Rational/ Literal		Critical		Hypothesising and Modelling	
	f	%	f	%	f	%	f	%	f	%
Freshmen	6	11.1	50	89.3	10	17.9	9	16.1	8	14.3
Seniors	5	8.2	56	91.8	13	21.3	17	27.9	7	11.4

Table 2. The distribution of graphical interpretation level for literacy graph

	Idiosyncratic		Basic Graph Reading		Rational/ Literal		Critical		Hypothesising and Modelling	
	f	%	f	%	f	%	f	%	f	%
Freshmen	17	30.3	39	69.6	7	12.5	18	32.1	1	1.8
Seniors	21	34.4	40	65.5	16	26.2	15	24.6	2	3.3

Discussion

Aoyama (2007) identified five different levels of interpretations of graphs: *Idiosyncratic, Basic Graph Reading, Rational/Literal, Critical, and Hypothesising and Modelling.* The first two of these levels focus on extracting specific value points from a graph. For these levels of interpretations of graphs, the desired information is explicitly represented in the graph and the graph reader is required only to locate and read the specific value points. The results of this study show that most of the pre-service science teachers can read the values and trends in the graph. This result may not be surprising because directly reading the values in the graph is not a difficult task (Doig & Groves, 1999; Espinel, Bruno, & Plasencia, 2008; Jacobbe & Horton, 2010; Sharma, 2006). Nearly 90% of the participants of the study could read the values directly given in the TV graph. However, only just under 65% of the participants could read the values in the literacy graph directly. The fundamental reason for this situation might be the types of the graphs. In the literature some researchers reported that types of graphs had effects on the students' interpretations of graphs (Baker, Corrbet, & Koedinger, 2001; Tairab & Al-Naqbi, 2004). The TV graph is a bar graph. The literacy graph is a scatter plot graph. The scatter plot graphs involve more cognitive operation than bar graphs. Bar graphs are usually more understandable, clear, and definite. The values in the axis and the relations between the variables in the axis are much more blurred in scatter plot graphs (Alacacı et al., 2011; Baker, Corrbet, & Koedinger, 2001). Also, the participants may not be familiar with scatter plot graphs becau se scatter plots are not dominant in the curriculum (Alacacı et al., 2011; Friel, Curcio, & Bright, 2001).

The third level of the interpretations of graphs hierarchy identified by Aoyama (2007) is *rational/literal.* Students who are able to accomplish this level can read the values in graphs and they can also explain contextual meanings of these values. If students cannot accomplish the tasks of this level, they cannot discover the hidden meanings in the values in graphs. The values in graphs are no more than small, meaningless knowledge points (Pfannkuch, 2006). The result of this study revealed that only a quarter of the pre-service science teachers are able to achieve the *rational/literal* level of the interpretations of graphs hierarchy. The Turkish pre-service science teacher training program might be the main reason of this negative result because in-class science teaching usually focuses on the quantitative aspects of graphs. Students struggle with quantitative data, mathematical computation, equations, statistical terms such as mode and median in the graphs throughout the lessons (Bayazıt, 2011; Connery, 2007; Espinel, Bruno, & Plasencia, 2008; Monterio & Ainley, 2007).

The fourth level of the interpretations of graphs hierarchy identified by Aoyama (2007) is *critical*. Students at this level can evaluate the hypothesis depending on the values and trends in graphs. The results of this study reveal that most of the pre-service science teachers (nearly 70%) do not critically evaluate information presented in a graph form. Aoyama states that it is not adequate for students to accomplish only Level 4 skills. In the 21st century, all citizens should take into account all the variations in the values presented in graphs and they should suggest their own alternative explanations. In other words, more citizens are expected to operate at Level 5 of the interpretations of graphs hierarchy. However according to findings of this study, very few of the pre-service science teachers (less than 15%) are able to interpret the graphs at the *hypothesising and modelling* level. This result might depend on various reasons. The last two levels in Aoyama's interpretations of graphs hierarchy are difficult tasks. These levels require thinking about the values and generating ideas about the conditions that are not explicit in the graphs. Many studies have found that it is not an easy task for learners to go beyond the explicit information in the graph (Aoyama, 2007; Bowen & Roth, 2005; Espinel, Bruno, & Plasencia, 2008; Glazer, 2011; Jacobbe & Horton, 2010; Shah & Hoeffner, 2002; Sharma, 2006). Individuals need the help of their teachers in order to cope with the demands of high level performances in the hierarchy of interpretations of graphs. Another reason might be that individuals must have prior knowledge about the context of the graph in order to suggest their own alternative explanations and criticize a hypothesis as presented (Aoyama, 2007; Glazer, 2011; Roth, 2004; Shah & Hoeffner, 2002; Vekiri, 2002; Wemyss & van Kampen, 2013). There are two graphs in the questionnaire used to collect data in this study. One of the graphs presents values about how many hours the children play TV games per day and how many acts of violence they experience. The other graph is formed of the values about the gross national product of countries and their literacy rates. We thought that the participants of this study would be familiar with the contexts of the two graphs because, these contexts are related to their professions. The findings lead us to believe that, contrary to our expectations, the participants were actually not familiar with the contexts.

When the freshman and senior pre-service science teachers' interpretations of graphs were compared, it was found that their interpretations of graphs were quite similar. In Turkey, pre-service science teacher training programs do not seem to promote the improvement of student teachers' interpretations of graphs. This result implies that interpretations of graphs are cognitive learning outcomes and teachers should teach interpretations of graphs with effective methods in their classrooms so that the students can accomplish a desired level of proficiency in graph interpretations.

Conclusion and Suggestion

At present, pre-service science teachers do not seem to be ready to teach interpretations of graphs in the way suggested by science education reform documents. Teaching modules that have the potential to promote interpretations of graphs of pre-service science teachers should be developed and implemented.

Pre-service science teachers are able to read the values in graphs explicitly, but they are not able to associate the values in a graph with the context. Moreover pre-service science teachers have difficulty in criticising ideas claimed to have been based on the value series in graphs. Also they are not able to construct their own hypothesis for values and trends presented in a graph. Learners should know the context of a graph. The result of this study can imply that pre-service science teachers might not be engaged in current issues to the degree needed for interpretation of graphs based on these issues. This suggests that teacher educators should provide the pre-service teachers with opportunities to explore such topics in their courses and they should guide the students in researching basic knowledge about current issues topics and in acquiring the skills needed to develop suggestions for solutions.

The questionnaire used in this study includes two types of graphs. One of them is a bar graph. The other is a scatter plot graph. The pre-service science teachers, both freshman and seniors, are better at interpreting bar graphs than scatter plot graphs. The science teachers have the key role for the promotion of children's interpretations of graphs so they should be familiar with various types of graphs. Our findings suggest that science teacher educators should identify what kind of graphs the pre-service teachers have difficulty in interpreting and then they should embed such graphs in their teaching in order to better prepare their students for their future profession.

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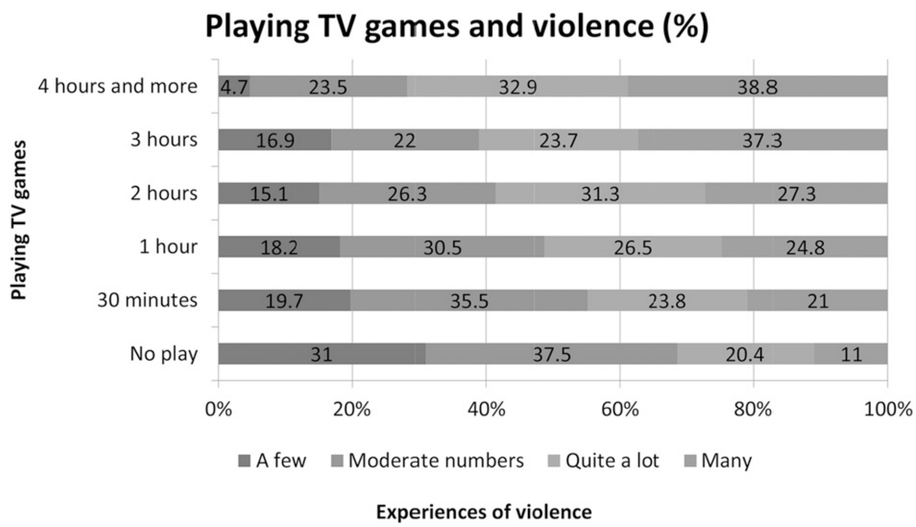
Acknowledgements: We would like to express our most sincere appreciation and thanks to Kazuhiro Aoyama for his support in the design of the instrument used in this study.

Appendix 1. Graphic Interpretation Questionnaire

TV games and violence graphic: The graphic below shows a research result that investigates how many hours per day elementary students play TV games at home and how many experiences of violence (e.g. hitting or pushing a classmate, pulling someone's hair) they have.



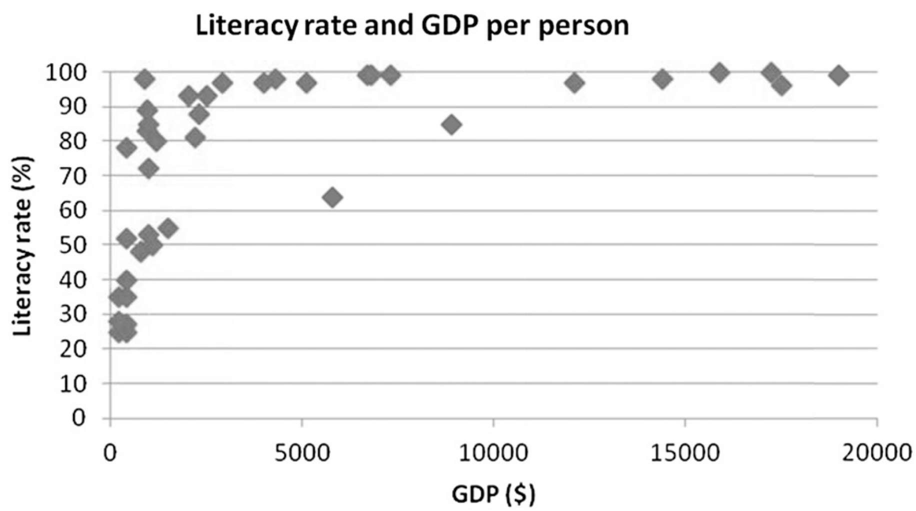
1. What percentages of the individuals who play a TV game for an hour in a day experience violence at the level of "quite a lot"?
……………………………………………………………………………………………………...

2. As the rate of TV games increases, how does the rate of the individuals who report "a few" experiences of violence change?
……………………………………………………………………………………………………...

3. An opinion such as, "Increasing use of spare time for TV games led to the increase in experiences of violence" is asserted. Do you agree with this opinion? Please specify reasons for your answer
a) Agree
b) Disagree
c) None
d) No idea
Because………………………………………………………………………………………….....

4. A hypothesis such as, "If the students are prevented from playing TV games, the violence incident experiences can be prevented, too" is claimed. Do you agree with it? Please specify your answer
a) Agree
b) Disagree
c) None
d) No idea
Because……………………………………………………………………………………………

The Gross Domestic Product (GDP) and the ratio of literacy: In the graphic below, the Gross Domestic Product per capita for 40 countries chosen randomly ($) and their literacy rates are seen.



1. How much is the Gross Domestic Product of the countries whose literacy rate is below 60%?
…………………………………………………………………………………………………...........

2. How can you explain the literacy rate of the countries whose Gross Domestic Product is high?
…………………………………………………………………………………………………...........

3. Do you think that there is a relation between the literacy rate and the Gross Domestic Product? If there is a relation, please explain what kind of relation is this?
a) There is a relation
b) There is not a relation
c) It is not so clear
d) No idea
Because: ……………………………………………………………………………………….......

4. Do you agree with the hypothesis, "If the Gross Domestic Products of the countries are increased, the illiteracy problem can be solved"? Please specify the reason for your answer with your justifications.
a) Agree
b) Disagree
c) None
d) No idea
Because……………………………………………………………………………………….............