Visual Symbolic Processing in Modern Times

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Abstract

Personal computers make diagram, chart, and graph creation technically a lot easier: just plug in some data, choose one of the pre-defined presentation styles, and the software application churns out a pretty looking illustration. The result is a proliferation of abstract visual information, miscomprehension of which might have serious personal and civic implications. The general consensus is that "a picture is worth a thousand words." But is it really true? In this paper, I examine the results from a small preliminary study which analyzes how much information individuals are able to extract from a set of complex diagrams and cross-reference it with public school instructional goals. In particular, visual symbolic processing is broken down into the ability to find information in a diagram; to use data in the diagram to generate new information; to create explanations of graphically presented information; to compare the usefulness of two diagrams presenting similar information; and to summarize the main ideas of a complex diagram. The subjects of this study ranged greatly in age and in levels of education. Yet, it was still apparent that higher level visual symbolic processing skills required in summarization and generation and inference of new information from existing data were the most difficult and led to the most numbers of communication failures. A surprising secondary result was a gender discrepancy in performance outcome, with female participants scoring significantly lower than their male counterparts. A planned larger study might shed more light on both outcomes.

Visual Symbolic Processing in Modern Times

Computer software has facilitated an explosion of graphically presented information. Newspapers, billboards, Web pages are all teaming with graphs, tables, maps, diagrams, and charts. The defacto consensus is that data presented in a visual way is easier to understand. But the skill to read and comprehend visually complex information is not an innate ability. Most people get their first exposures to abstract visual information as early as Kindergarten. While aspiring to more, public schools tend to teach very simple graph skills: plot points on a 2-D plane; create bar diagram; read pie charts; and, in the higher grades, graph an equation. These tend to be lower level visual symbolic processing skills. In the real world, individuals are asked to compare complex sets of data presented as charts or graphs; to interpret the meaning of visual data; and summarize the key ideas shown in a graphical way. More importantly, in the real world, individuals have to make important personal and civic decisions based on graphical information and their understanding of its implications (e.g.: personal health choices; tax decisions; election issues; etc.). These tasks require higher order visual symbolic processing skills.

Visual Symbolic Processing Analysis

Spatial visual perceptual processing deals with the ability to figure out a visual pattern and to arrange visual information spatially. Sequential perceptual processing allows to observe and understand ordered chains of information—strings of data that have sequential patterns or a particular arrangement in time. The sequential processing system tends to be located on the left side of the brain, the spatial processing system on the right. Both are necessary to comprehend abstract visual representations of information.

People with poor sequential processing have trouble in making and keeping schedules. They are always late and have poor time management skills. These people might also have trouble understanding a sequence of instructions, have issues with recipes, and are poor at following directions (Levine, M., 2002).

People with poor spatial processing tend to have closets that look like there has been an explosion of socks. They have trouble managing and keeping track of their possessions. Their desks look like a mess. And they tend to have problems reading visual information—graphs are difficult, tables are hard, mathematical equations seem out of reach.

There are wide differences between individuals in their abilities to interpret, store, and communicate sequential and spatial visual information. Clearly, if a person has poor sequential and spatial perceptual processing skills, he/she will have trouble remembering such information and will experience stress when forced to deal with sequential or spatial information, further burdening his/her already overwhelmed working memory (Jonassen, D. H., Grabowski, B. L., 1993).

The interaction with sequential and spatial visual information can be broken down into:

- perceiving—an ability to figure out a pattern of sequentially or spatially arranged visual data;

- remembering—the ability to remember a sequential or spatial pattern of visual information;
- making—the ability to create, organize, or arrange information in a sequential or spatial visual pattern;
- thinking—the ability to problem solve, to reason, and to think critically about sequential or spatial visual information.

An individual can be good at remembering sequential or spatial patterns of information, but be lousy at creating such patterns—there are many more good readers than there are good writers.

Visual Symbolic Processing Skills

In order to analyze individual's visual symbolic processing ability, I've organized them into higher and lower order skills. *Lower order skills* include:

- find visual information—the ability to find discrete information explicitly presented by a diagram;
- understand and explain visual information—the ability to read and understand the meanings of axis, units, and labels in a diagram and what they represent.

Lower order visual symbolic processing skills require an individual to carefully read the different parts of the diagram, but not to generate any new information based on the data presented by the diagram—a person doesn't need engage in abstract visual problem solving.

The ability to process visual symbolic information deeply enough to generate or infer new information not obviously available in the diagram I call *higher order visual symbolic processing skills.* While lower order visual symbolic processing skills are generally taught in schools as part of the math and science curricula, higher order visual symbolic processing skills are not explicitly learned until much later if at all. Higher order visual symbolic processing skills include:

- use visual information to generate new information—the ability to use data flexibly and to generate additional information based on visual data presented in a diagram;
- summarize visual information—the ability to convert visual data into a language-based story (requires deep understanding of the information);
- compare multiple visual representations—the ability to convert information found in one diagram into data structures of another diagram and assign a value judgement on the quality and usefulness of each presentation.

Testing Visual Symbolic Processing Skills

To be able to understand the distribution of visual symbolic processing skills, I created a test. This test consists of several complex diagrams accompanied by a series of multiple choice and fill-in questions. This test focused only on the ability to read and understand visual symbolic information, not to create it. These questions are categorized based on the skills they are assessing:

Lower order skills—6 questions total

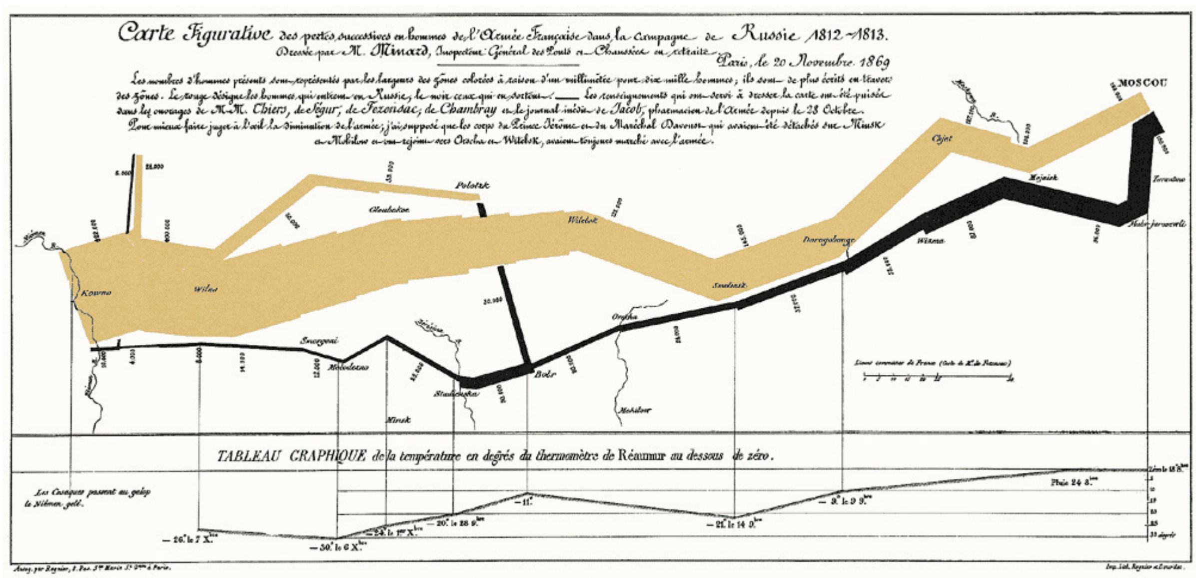
- find visual information—5 questions
- understand and explain visual information—1 questions

Higher order skills—9 questions total

- use visual information to generate new information—5 questions
- summarize visual information—4 questions
- compare multiple visual representations—1 question

For the test, I used real diagrams, representing real data. These diagrams were of historical origins and most of the labels were written in French. The latter choice was to control the information to which the study participants were exposed. I've carefully written directions that accompanied each question and each diagram so as to focus the responses along the categories described above. None of the participants were French speaking.

The first six questions were based on Minard's famous diagram of Napoleon's march to and from Moscow in 1812-1813 (Tufte, E. R., 1990), see below. The other nine questions included the Pythagorean table and its more complex companion, the graph depicting the distribution of temperatures over a two year period, a chart showing the fluctuations in English debt over several decades, and a slide-ruler type multiplication table diagram.



Charles Joseph Minard's graphical representation of the story of Napoleon's advance and retreat into Russia in 1812. Source: http://www.edwardtufte.com/tufte/posters

The test was designed to be taken in under an hour, and individuals were encouraged to check their work for accuracy without time pressure. Subjects ranged in ages from ten years of age to over forty. Each person was asked to provide the last available grade in a math class they took.

The visual comprehension test was followed by a question designed to elicit information about perceptual learning preference of the subject. Depending on their answers, individuals could have potentially been labeled as visual learners, audio learners, haptic learners, or as having no strong preference. The resulting data from this last questions weren't fine grained enough to generate useful information.

The ability to express one's thoughts in a grammatical English was not part of the test. As long as the language didn't interfere with the ability to understand the content of the answer, the answer was marked correct. Each question had a set of acceptable parameters within which it was either accepted as correct or rejected as wrong.

Results

This paper presents only the small scale study results. Only 13 subjects were given the test: 5 females and 8 males. The age (12 years of age to over 40) was not the limiting factor and didn't correlate closely to the number of questions answered correctly. Similarly the perceptual learning preference (visual, audio, or haptic) didn't have much predictive power on the outcome of the score. The performance in a math class (getting an "A" or a an "F" in the last math class taken, for example) also didn't matter. The largest differences were, as expected, due to the types of question asked: questions that tested either lower or higher level visual symbolic processing skills. An unexpected preliminary result showed that the scores were significantly lower for the 3 female participants (also irrespective of their math skills). Since the number of subjects was very small, it might be just a coincidence. Future data results based on this test will shed more light on this issue.

	Lower Level Skill		**Higher Level Skill**			**Total # = 13 Male = 8 and Female = 5**		
Question #	**Find Info**	**Explain Info**	**Get New or Infer Info**	**Compare Info**	**Summarize or Synthesize Info**	**# Right /Total**	**# Right /Male**	**# Right /Female**
1		**X**				**7 out of 13**	**7 out of 8**	**0 out of 5**
2	**X**					**9 out of 13**	**5 out of 8**	**4 out of 5**
3			**X**			**5 out of 13**	**4 out of 8**	**1 out of 5**
4	**X**					**12 out of 13**	**8 out of 8**	**4 out of 5**
5			**X**			**6 out of 13**	**5 out of 8**	**1 out of 5**
6					**X**	**6 out of 13**	**3 out of 8**	**3 out of 5**
7		**X**				**11 out of 13**	**7 out of 8**	**4 out of 5**
8-I		**X**				**11 out of 13**	**7 out of 8**	**4 out of 5**
8-II				**X**		**7 out of 13**	**3 out of 8**	**4 out of 5**
9			**X**			**8 out of 13**	**5 out of 8**	**3 out of 5**
10	**X**					**10 out of 13**	**7 out of 8**	**3 out of 5**
11			**X**			**8 out of 13**	**5 out of 8**	**3 out of 5**
12			**X**			**3 out of 13**	**3 out of 8**	**0 out of 5**
Total # Right	**9.3 / 13 or 71.5%**	**9.7 / 13 or 74.6%**	**6 / 13 or 46.2%**	**7 / 13 or 53.8%**	**6 / 13 or 46.2%**	**7.5 out of 13 > 50%**	**5.1 out of 8 > 50%**	**2.4 out of 5 < 50%**
Male	**6.25 / 8 or 78.1%**	**7 / 8 or 89.3%**	**4.3 / 8 or 53.8%**	**3 / 8 or 37.5%**	**3 / 8 or 37.5%**			
	6.6 / 8 or 82.5%		**3.4 / 8 or 42.5%**					
Female	**3 / 5 or 60%**	**2.7 / 5 or 54%**	**1.7 / 5 or 34%**	**4 / 5 or 80%**	**3 / 5 or 60%**			
	2.9 / 5 or 57%		**2.9 / 5 or 58%**					
Total # Right	**9.5 out of 13 or 73.1%**		**6.3 out of 13 or 48.5%**					

	Lower Level Skill		Higher Level Skill			Total # = 13 Male = 8 and Female = 5		
Question #	Find Info	Explain Info	Get New or Infer Info	Compare Info	Summarize or Synthesize Info	# Right /Total	# Right /Male	# Right /Female
13	X					6 out of 13	5 out of 8	1 out of 5
14			X			6 out of 13	4 out of 8	2 out of 5
15					X	5 out of 13	3 out of 8	2 out of 5
Total # Right	9.3 / 13 or 71.5%	9.7 / 13 or 74.6%	6 / 13 or 46.2%	7 / 13 or 53.8%	6 / 13 or 46.2%	7.5 out of 13 > 50%	5.1 out of 8 > 50%	2.4 out of 5 < 50%
Male	6.25 / 8 or 78.1%	7 / 8 or 89.3%	4.3 / 8 or 53.8%	3 / 8 or 37.5%	3 / 8 or 37.5%			
	6.6 / 8 or 82.5%		3.4 / 8 or 42.5%					
Female	3 / 5 or 60%	2.7 / 5 or 54%	1.7 / 5 or 34%	4 / 5 or 80%	3 / 5 or 60%			
	2.9 / 5 or 57%		2.9 / 5 or 58%					
Total # Right	9.5 out of 13 or 73.1%		6.3 out of 13 or 48.5%					

This table presents individual and summative data for the questions given in the visual comprehension test. There were a total of 15 questions, question 8 had two parts which were assessed separately. The preliminary study had only 13 subjects: 5 females and 8 males.

The chart above shows how the questions were answered and to which category of visual symbolic processing skills they belonged. The lower level skill questions averaged a higher number of people answering the them correctly (9.5) than the higher level skill questions (6.3).

As can be seen from the above table, only 48.5% of the total number of participants were able to answer higher level questions correctly. But these differences totally dissapear for female subjects: 57% of all female participants answered the lower level skill questions correctly as compareed to 58% for higher level skill questions. And also suprising, the difference in performance between a lower and higher level skill questions got even more extreame for male subject: 82.5% versus 42.5% respectively. Lower level questions were easier for male population.

In particular, the one question designed to test the ability to explain information of a diagram (question #1) had zero success rate for the girls, but seven out eight boys were able to answer it correctly. Similarly for question number twelve which required the subjects to generate new information based on the data presented in a graph. Not a single female participant was able to answer the question correctly, but more than a third of male subjects could. The males subjects did significantly better, averaging 6.6 out of 8 for lower level skill questions (or 82.55%).

Male subjects were also more enthusiastic about taking the test and viewed it as an interesting challenge. Female participants didn't seem to feel this way, were very reluctant to participate, and took a long time to get started. It's not clear why there is a discrepancy in performance and attitude, and this outcome was not anticipated. I look forward to finding out if a larger study will change this result.

While it would be inappropriate to make a lot of inferences with so little data, the difference in performance between the lower and higher level skill questions was statistically significant. In particular, getting new information from a diagram or making inferences was very difficult. And while there didn't seemed to be any relationship between individual's perceptual learning orientation based on these outcomes, it might have more to do with a poor quality of the assessment tool designed to elicit such information. Given a larger sample and a better perceptual learning orientation assessment tool, the results might be quite different. Since this study was preliminary, there were very few subjects. A larger run is planned for next year. Anyone interested in participating in the study is urged to visit http://www.EdEvaluation.com/moodle and take the Visual Comprehension Test.

Discussion

We live in a society that values visual information: "I have to see it to believe." and "A picture is worth a thousand words." And since personal computers make tables, charts, and graphs very easy to generate, people get bombarded with complex abstract visual information in all areas of their lives from political poll data to investment brochures to medical service announcements. We are asked to make important civic, financial, and health decisions based on such visual information. But is an average person well equipped to deal with such information? From this preliminary study, the answer seems no.

In United States, students are required to learn how to read and generate graphs as part of their math and science curricula. While each state has their own framework for Curriculum Content Standards, I used California version as a baseline for this article since all of the subjects for this study grew up in this state: http://www.cde.ca.gov/be/st/ss/. Appendix provides a table linking California Curriculum Content Standards in Mathematics and Science with required abilities needed to understand them.

The table below relates the higher and lower visual processing skills identified in the study with the California Curriculum requirements. The required abilities (see Appendix) are converted into receptive capabilities necessary for comprehension of abstract visual information.

	Skills Tested by the Study	Skills Taught in California Schools	Year Introduced
Higher Order Abstract Visual Processing Skills	**use visual information to generate new information**—the ability to use data flexibly and to generate additional information based on visual data presented in a diagram	• Create bar graphs. • Create network diagrams. • Construct and interpret graphs. • Use graphs for estimation. • Construct simple branching diagrams. • Develop graphical solutions.	1st grade 4th grade 4th grade 6th grade 7th grade 8th grade
	summarize visual information—the ability to convert visual data into a language-based story (requires deep understanding of the information)	• Model problems through sketching. • Communicate visually. • Draw descriptions. • Create graphical representations of data. • Use abstract graphical representations to explain scientific knowledge. • Display data visually.	K K 2nd grade 5th grade 7th grade 7th grade
	compare multiple visual representations—the ability to convert information found in one diagram into data structures of another diagram and assign a value judgement on the quality and usefulness of each presentation	• Reason with pictorial representations. • Describe and compare data. • Use abstract graphical representations to explain mathematical reasoning. • Analyze graphical information. • Use graphs for communication.	K 3rd grade 4th grade 8th grade 8th grade
Lower Order Abstract Visual Processing Skills	**find visual information**—the ability to find discrete information explicitly presented by a diagram	• Record data. • Understand a complex abstract graphical table. • Read abstract maps. • Understand functions, coordinates, points, slope and point-slope in a graph.	1st grade 5th grade 5th grade 8th grade
	understand and explain visual information—the ability to read and understand the meanings of axis, units, and labels in a diagram and what they represent	• Measure using different units. • Understand a complex abstract graphical table.	2nd grade 8th grade

This tables shows when these different visual processing skills are introduced into California math and science curricula. Both higher and lower level abstract visual processing skills are introduced as early as Kindergarten.

Based on the California Curriculum Content Standards in Mathematics and Science, students are introduced to visual abstract communication at the start of their educational careers and are required to know and understand how to construct graphs and record data as early as first grade. Since the youngest participant in this study was a seventh grader, it is evident that these skills take a long time to develop.

The basic implications of this study is that comprehension of abstract visual information is hard. People have difficulties pulling out key data from the diagrams and even more problems using the information flexibly. Even with a strong agenda to teach visual communication skills, schools fail to develop those skills among their student populations. And students are able to sail through their math and science courses with good grades but without a good grasp of skills necessary to read, use, or produce abstract visual representations of data.

Summary

In this study, I only test receptive abstract visual comprehension capabilities (i.e. ability to understand rather than create abstract graphical information). In theory, it should be much easier to understand than to generate abstract visual information—if an individual can't understand the meaning of the graph, he/she shouldn't be able to create it. But given the range of computer software available today, this is clearly no longer true. Following a set of prompts, a person can easily generate any number of graphs, charts, tables, and diagrams without full (or even partial) comprehension. On the other hand, it can be argued that given the ease of generation, people are more used to abstract visual information. The preliminary results, though, show that such familiarity doesn't translate into comprehension.

Some results of the study are clearly predictable: the performance on the lower level visual comprehension skills was much better than on the higher ones (but only in male subjects). Since higher level skills require individuals not only to perceive, remember, and grasp the basic information in the diagram but to actually manipulate visual data and to problem solve, it is not a surprise that the scores are significantly lower for the questions requiring those skills.

The gender variation is clearly the surprising outcome of this study. Since this is only a preliminary study and quite small in scope, I hope this result will turn out to be a simple statistical fluctuation. If not, the discrepancies in performance due to gender need to be understood and addressed in the classrooms and in the presentation of visual materials destined for the mass media. *Complex abstract visual information is only a tool of communication when it is understood by its intended audience.*

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Appendix

California Content Standards can be found at California State Board of Education Web site: http://www.cde.ca.gov/be/st/ss/. California's Mathematics Curriculum Content Standard was adapted in December of 1997. California's Science Curriculum Content Standard was adapted in October of 1998.

The table below describes California's expectations of students attending public schools, from Kindergarten through eighth grade (Geometry is usually taught in ninth grade). Italics are added to highlight the skills and concepts that are required for visual explanations, charts, tables, and graphs. The complete list can be found at http://www.cde.ca.gov/be/st/ss/.

Grade	CA Curriculum Content Standard	Required Ability
K	**Science** 4.e. Communicate observations orally and through *drawings*. **Mathematics** 1.2 Use tools, such as manipulatives or sketches, to *model problems*. 2.1 Explain the reasoning used with concrete objects and/ or *pictorial representations*.	1. Communicate visually. 2. Model problems through sketching. 3. Reason with pictorial representations.
1	**Science** 3.a. ... *record* changes from day to day and across the seasons. 4.b. *Record* observations and data with pictures, numbers, or written statements. 4.c. Record observations on a *bar graph*. **Mathematics** 1.2 Use tools, such as manipulatives or sketches, to *model problems*. 2.1 Explain the reasoning used with concrete objects and/ or *pictorial representations*.	1. Record data. 2. Create bar graphs. 3. Model problems through sketching. 4. Reason with pictorial representations.
2	**Science** 4.b. Measure length, weight, temperature, and liquid volume with appropriate tools and express those measurements in standard metric system units. 4.d. Write or *draw descriptions* of a sequence of steps, events, and observations. 4.e. *Construct bar graphs* to record data, using appropriately labeled axes. **Mathematics** 1.2 Use tools, such as manipulatives or sketches, to *model problems*.	1. Measure using different units. 2. Draw descriptions. 3. Create bar graphs. 4. Model problems through sketching.
3	**Science** 5.c. Use numerical data in describing and comparing objects, events, and measurements. **Mathematics** 1.2 Use tools, such as manipulatives or sketches, to *model problems*.	1. Describe and compare data. 2. Model problems through sketching.
4	**Science** 2.b. ...know producers and consumers...are related in *food chains and food webs*... 6.e. *Construct and interpret graphs* from measurements. **Mathematics** 2.3 Use a variety of methods, such as words, numbers, symbols, *charts, graphs, tables, diagrams, and models*, to explain mathematical reasoning.	1. Create network diagrams. 2. Construct and interpret graphs. 3. Use abstract graphical representations to explain mathematical reasoning.
5	**Science** 1.d. ...elements are organized in the *periodic table* by their chemical properties. 4.d. ...use *weather maps* and data to predict local weather... 6.g. Record data by using appropriate *graphic representations* (including *charts, graphs, and labeled diagrams*) **Mathematics** 2.3 Use a variety of methods, such as words, numbers, symbols, *charts, graphs, tables, diagrams, and models*, to explain mathematical reasoning.	1. Understand a complex abstract graphical table. 2. Read abstract maps. 3. Create graphical representations of data. 4. Use abstract graphical representations to explain mathematical reasoning.

Grade	CA Curriculum Content Standard	Required Ability
6	**Science** 7.c. *Construct appropriate graphs* from data and develop qualitative statements about the relationships between variables. 7.d. *Communicate* the steps and results from an investigation in written reports and oral presentations. **Mathematics** 2.3 Estimate unknown quantities *graphically* and solve for them by using logical reasoning and arithmetic and algebraic techniques. 2.4 Use a variety of methods, such as words, numbers, symbols, *charts, graphs, tables, diagrams, and models*, to explain mathematical reasoning.	1. Construct graphs. 2. Communicate visually. 3. Use graphs for estimation. 4. Use abstract graphical representations to explain mathematical reasoning.
7	**Science** 3.d. ...construct a *simple branching diagram* to classify living groups of organisms by shared derived characteristics and...expand the *diagram* to include fossil organisms. 7.a. Select and use appropriate tools and technology...to perform tests, collect data, and *display data*. 7.d. Construct scale *models*, *maps*, and appropriately labeled *diagrams* to communicate scientific knowledge... 7.e. *Communicate* the steps and results from an investigation in written reports and oral presentations. **Mathematics** 2.3 Estimate unknown quantities *graphically* and solve for them by using logical reasoning and arithmetic and algebraic techniques. 2.5 Use a variety of methods, such as words, numbers, symbols, *charts, graphs, tables, diagrams, and models*, to explain mathematical reasoning.	1. Construct simple branching diagrams. 2. Display data visually. 3. Use abstract graphical representations to explain scientific knowledge. 4. Use graphs for estimation. 5. Use abstract graphical representations to explain mathematical reasoning.
8	**Science** 1.f. ...*interpret graphs* of position versus time and graphs of speed versus time for motion in a single direction. 3.f. ...use the *periodic table* to identify elements in simple compounds. 9.d. Recognize the *slope* of the linear graph as the constant in the relationship y=kx and apply this principle in *interpreting graphs* constructed from data. 9.e. *Construct appropriate graphs* from data and develop quantitative statements about the relationships between variables. 9.g. Distinguish between linear and nonlinear relationships on a *graph* of data. **Algebra I** 7.0 ...verify that a point lies on a line, given an *equation of the line*...derive linear equations by using the point-*slope* formula. 8.0 ...understand the concepts of *parallel* lines and *perpendicular* lines and how those *slopes* are related... 9.0 ...solve a system of two linear equations in two variables algebraically and are able to *interpret the answer graphically*...solve a system of two linear inequalities in two variables and to *sketch the solution sets*. 17.0 ...determine the domain of independent variables and the range of dependent variables defined by a *graph*, a set of ordered pairs, or a symbolic expression. 18.0 ...determine whether a relation defined by a *graph*, a set of ordered pairs, or a symbolic expression is a function and justify the conclusion.	1. Interpret graphs. 2. Understand a complex abstract graphical table. 3. Understand the meaning of slope. 4. Use graphs for communication. 5. Understand functions, coordinates, points, slope and point-slope in a graph. 6. Develop graphical solutions. 7. Analyze graphical information.

This tables shows the expectations from an average California student to create and understand abstract graphical information.