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ABSTRACT

This paper identifies and assesses key ideas in data analysis (or statistics) that should be at the focus of middle school mathematics instruction. Items that can be used to assess some of the complex objectives of data analysis are located. The search includes a collection of items released by the National Assessment of Educational Progress (NAEP) and various state exams. The nature of items being used on large-scale state assessments is described in detail. Views on what should be taught and some items that are designed to tap those ideas are presented. (SOE)

If U Can Graff These Numbers — 2, 15, 6 — Your Stat Literit

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If U Can Graff These Numbers — 2, 15, 6 — Your Stat Literit

Consider these proposed objectives for what eighth grade students should know about working with data:

1. Given any of a variety of common graphs or tables, including bar graphs, time series, and two-by-two tables, students will be able to read off the value of a specified case and to give the number (or percent) of cases of a specified type.
2. Given a number of values or a graph, students will be able to determine from them statistics including the mean, median, mode, and range.

Probably all of us would agree that eighth grade students should be proficient in these two sets of skills. But few of us would likely regard these skills as being even close to comprising *all* of what we would expect of them. Despite this, we appear to have reached a national consensus that instruction in data analysis up to the middle school should be primarily concerned with these very basic computation and graph reading skills. The primary evidence for this consensus is the fact that nearly 80% of the items on high-stakes tests released by various states target these two objectives.

In this paper we report on our ongoing efforts to identify and assess key ideas in data analysis (or statistics) that we maintain should be at the focus of middle school instruction. It was in the hopes of locating items that we could use to assess some of these more complex objectives that we searched the collection of items released by the National Assessment of Educational Progress (NAEP) and the various states. Below, we first describe in more detail the nature of items being used on large-scale state assessments. We then offer some of our views on what we should be teaching and present some items that we are designing to tap these ideas.

What the High-Stakes Tests Are Assessing

To get a sense of the nature of items currently being used to assess competencies in data analysis, we searched on the sites of states that conduct large-scale assessments of their students. We confined our search to items targeted to grades 6 – 10. Many states have items available from several different years, and in such cases we looked only at those items from the most recent year available. We also looked at the items administered by NAEP for grades eight in 1990 , 1992, and 1996.

We located 264 items from the high-stakes tests of 41 states that fit the above criteria. Roughly 41% of these items were described as sample items, 10% were released practice items, and the remaining 49% were released items that had appeared on the most recent administration of the state's assessment. We also located 10 items on data analysis from past administrations of NAEP. This gave us a total of 274 items.

We coded the 274 items as either "encode/decode" or "other." In broad terms, we included in the encode/decode category items that asked students to convert raw data into a statistic or display (table or graph), or to do the reverse — to determine from a data display or a statistic the corresponding data values or frequencies. Figure 1 is an example of an item that tests the ability to compute a mean from a set of values, and Figure 2 tests the ability to determine from a case value bar graph the case with the largest value.

Insert Figures 1 and 2 about here

In terms of the distinctions among data skills suggested by Curcio (1987), the encode/decode category corresponds roughly to her descriptor "reading the data." As we attempted to communicate in the two objectives in our introduction, these items probe students' knowledge of conventions for representing data graphically and of summarizing data with various measures such as frequencies, relative frequencies, means, ranges, etc.

Of the 274 items we analyzed, 78% of the them target encode/decode skills. Table 1 lists the states we obtained items from and shows the breakdown of items of each type. The states are ordered in the table according to the percentage of encode/decode items. We obtained only a few items from many of the states, and for these states the percentages of encode/decode items are questionable indicators of the pattern of items on their assessments. Accordingly, we divided the states into two groups in Table 1: those from whom we located more than 5 items (top) vs.5 or few items (bottom). We obtained 10 or more items for Minnesota, Mississippi, Ohio, Texas, and Georgia, and in each of these states, over 90% of the items target skills at the encode/decode level. In contrast, we obtained 12 items from Kansas where fewer than half of them were directed at encoding/decoding skills. Five of the ten items from NAEP were of the encode/decode variety.

For the most part, items that we coded as "other" tended to assess higher level skills, such as ideas related to sampling, scaling, predicting, choosing between using different averages in particular situations, and making decisions or recommendations from the data and justifying these. However, this category also included items that in our opinion do not involve data analysis. Figure 3 and 4 includes two examples. The item in Figure 3 asks students to make a recommendation that satisfies several mathematical constraints. The reason we think it was considered as involving data analysis was that the information the students were to consider was presented in a table which the students had to use correctly if they were to extract the relevant information.

Insert Figure 3 about here

Similarly, the item in Figure 4 asks students to locate a value on a linear function, and our guess is that it was considered data analysis by virtue of its being a graph. In looking at a number of items like these and the objectives they supposedly assess, our sense is that some test developers are interpreting "data analysis" more generally as the organization of *information* ,where the information that is organized need not involve data in the statistical sense.

Insert Figure 4 about here

Higher-Level Objectives And Items

Based on our analyses, it appears that our current high-stakes assessments are virtually ignoring all but the most rudimentary skills involved in data analysis. We assume that at least part of the reason for this neglect results from a lack of clarity about what the higher-level objectives in data analysis might be or about how one might assess these objectives using formats appropriate for wide-scale testing. Accordingly, we offer below our view on larger objectives and ways to assess them.

We do not attempt to enumerate what we think the objectives in data analysis at the middle school should be. Rather, we focus on three overarching ideas and related skills that we believe should be near the top of such a list. These are:

1. comparing two groups,
2. judging the relationship between two attributes, and
3. the understanding that as a sample grows, measures of group characteristics from that sample become more stable and thus more informative.

The first two objectives are described in the National Council of Teachers of Mathematics (NCTM) *Principles and Standards for School Mathematics* (2000) for the middle school under the heading "Develop and evaluate inferences and predictions that are based on data." The Standards suggest that:

> In collecting and representing data, students should be driven by a desire to answer questions on the basis of data. In the process, they should make observations, inferences, and conjectures and develop new questions (p. 251-252).

The Standards break this down into the more specific expectations that in these grades students should:

- use observations about differences between two or more samples to make conjectures about the populations from which the samples were taken;
- make conjectures about possible relationships between two characteristics of a sample... (p. 248)

It is interesting to note that these expectations speak of making "inferences," and yet formal inferential techniques (i.e., t-tests, Chi-square, confidence intervals) are not part of the Standards for the middle school. Our own view is that we ought to be helping elementary and middle school students develop ideas that support making inference from samples and which are precursors to formal tests of inferences. The understanding outlined in objective 3 above is such an idea.

We should add that our main reason for developing these items is to use them to help gauge the effectiveness of instructional materials we are developing, and in this effort we are collaborating with several other statistics education projects. Our initial hope was that we could use items that had appeared on the high-stakes tests for our purposes and began developing our own only after we found so few that targeted higher-level objects. But we also hope as part of this effort to nudge the more general discussion of what the key ideas of data analysis are and how we can help our students develop them. Developing items that we can all agree assess those ideas not only gives us a means of gauging our progress; the step of translating our vision into assessment items is a critical part of the process of conceptualizing those objectives.

Group Comparison

Making comparisons between two groups is perhaps the most fundamental and widely employed technique in statistics. One of the hopes in integrating data analysis into the K-12 curricula is that our citizens will become more facile with interpreting the bombardment of claims they encounter about one option being better than another.

The item in Figure 5 is from the 2001 Kansas Curricular Standards for Mathematics. The first part of the question asks the student to construct boxplots from stem and leaf plots. We would regard this first part as involving decoding and encoding. The second part asks for a judgment about the two groups. This is one of the few items we found in our search that asks for a group comparison, though the question as worded "what inferences could be made…" is so open ended that we imagine it would prove difficult to score.

Insert Figure 5 about here

A notable feature of the problem is that it provides information in a key that might help a student unfamiliar with stem and leaf plots to decipher them. Furthermore, we assume that students who could not construct a box plot could still demonstrate proficiency in comparing the two groups on the second part of the item by interpreting the stem and leaf plot (but we did not have access to a scoring protocol to verify this). For the items we have been developing to assess higher level objectives, we have tried to use plots that research suggests are relatively easy for students to decode (Bright & Friel, 1998; Feldman, Konold, & Coulter, 2000). Our intention is to separate the question of whether a student can decode a particular plot from the question of whether he or she can perform a more complex analysis based on it. Among other things, this allows us to use the item to assess student reasoning before instruction.

Figure 6 shows a problem we are developing to assess the ability to formulate a valid comparison between two groups, in this case to decide which of two headache remedies works faster. We have adapted this item from a protocol we developed and used in a series of clinical interviews (see Konold, in preparation).

Insert Figure 6 about here

Acceptable responses to this item would include claims that the new drug is better because e.g., "The average time to relief for people taking the new drug appears to be less" or that "The majority of those taking the new drug got relief in less than 1 hour compared to a small minority of those taking the old drug." Both of these responses entail using a measurement for each group that is derived from all the data in that group (an average or a percentage). Based on research with similar problems, we know that many students working with data and displays like these employ comparison methods that use only small subsets of the data (Gal, Rothchild, & Wagner, 1990; Konold, Pollatsek, Well, & Gagnon, 1997; Watson & Moritz, 1999). These methods include comparing numbers of cases in the two groups:

1. in small slices ("The new drug is better because with it there were about 10 people who got relief in 50 minutes compared to only about 3 people with the old drug.")
2. in one of the extremes ("The old drug is better because the two people who got the fastest relief used the old drug."), or
3. relative to a cut point ("The new drug is better because about 20 or 30 of that group took over 80 minutes compared to only 4 taking the new drug.").

We use different sample sizes in the two groups so that methods based on comparing numbers rather than percentage of cases will be problematic. We also include extreme values that contradict the overall trend such that the group with the lower mean has the highest two values and the group with the higher mean has the lowest two values. Otherwise the spread and shape of the two groups are relatively similar so that comparing groups based on their averages is reasonable (see Konold & Pollatsek, 2002).

Judging Relationships

Judging whether and how two attributes are related is another critical skill included among the objectives for middle school students. Figure 7 shows one of the items we are developing to assess this capability. In this case, the student must critique four possible plots with respect to this summary. We expect that after field testing the item we will revise it to ask simply that students select the option that most closely corresponds to the verbal summary.

Insert Figure 7 about here

One major difference between this item and the item presented in Figure 3 is that here students must not only read a point, but attend to the trend. Furthermore, the trend is not linear and it is a noisy one, with plenty of variability. It is the later feature that makes this a statistical problem rather than purely mathematical one. Because of all the exceptions to the trend, it is not so straight forward to perceive and describe it.

One of the shortcomings of this particular item is that we know that the scatterplot is not a particularly easy representation for students to decode (see Batanero, Estepa, & Godino, 1997; Cobb, McClain, & Gravemeijer , in press; Konold & Higgins, 2003; Noss, Pozzi, & Hoyles, 1999). We are developing other items that make use of alternative representations that students appear to be able to interpret with much less difficulty (see Konold, 2002).

Stability of Measures from Large Samples

One of the fundamental ideas in statistics is that as an appropriate sample gets larger, various properties of its parent population become more visible. These properties include the location of the mean, median, measures of spread such as the standard deviation and interquartile range, as well as the overall shape of the distribution. This insight provides the basis for trusting that samples give us useful information about populations and thus for making inferences about the population from the sample. Our own sense is that the middle school curricula could do more to help develop this insight. Lehrer and his colleagues have developed and tested a number of classroom activities which demonstrate that even elementary grade students are quite capable of understanding and applying this concept (e.g., Lehrer, Schauble, Strom, and Pligge, 2001).

Insert Figure 8 about here

We designed the item in Figure 8 to assess the idea that random samples of the same size will basically resemble one another. The item presents a sample of the weights of backpacks of 40 randomly chosen individuals. The student must pick from among four alternative stacked dot plots the plot most likely to result from adding another 40 data points to the sample. From classroom field tests with a similar situation (see Konold & Pollatsek, 2002, pg, 283-384), we know that some students will maintain that in a new sample anything is possible and that therefore they have no expectations about the outcome. (We are adding to this item the option that there is no reason to favor one graph over another.) Others student argue (correctly) that as the sample grows in size, the range will tend to grow larger. But these students also often expect that the distribution will in general become more flattened (option a). Option b is perhaps too subtle, but we included it to capture the thinking of those who believe that the second sample would be identical to the first. Option c is consistent with the expectation that many hold that as a sample gets larger, all aspects of it also get larger (including, for example, the mean).

Conclusions

Earlier, we speculated that the reason current high-stakes tests focus almost exclusively on low level capabilities in data analysis is that either they have a different view of what data analysis is or they have concluded that higher level skills are difficult to assess in item formats appropriate for standardized test. But it may also be that the test developers have consciously decided to assess only the most rudimentary skills, perhaps because they are fearful that most students would be incapable of any more than that. What ever the reasons for the status quo, the make up of current large-scale assessments in our opinion is serving to hinder the development of statistical literacy in our students. Once in place, these items as a collection serve to communicate to all the stakeholders what the real objectives are. It becomes increasingly difficult in this environment to develop and test new approaches and objectives, because teachers feeling the pressure to prepare students to do well on these assessment are understandably loath to devote class time to topics or skills that are not directly covered on them.

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Appendix: Tables and Figures

Figure 1. Grade 10 released test item from Louisiana's GEE 21 (Graduation Exit Examination for the 21st Century), July 2002.

Roy compared the price of a tape player at 5 stores. The prices at the different stores were $80.00, $95.00, $60.00, $90.00, and $85.00. What was the average (mean) price of the tape players?

a. $415.00

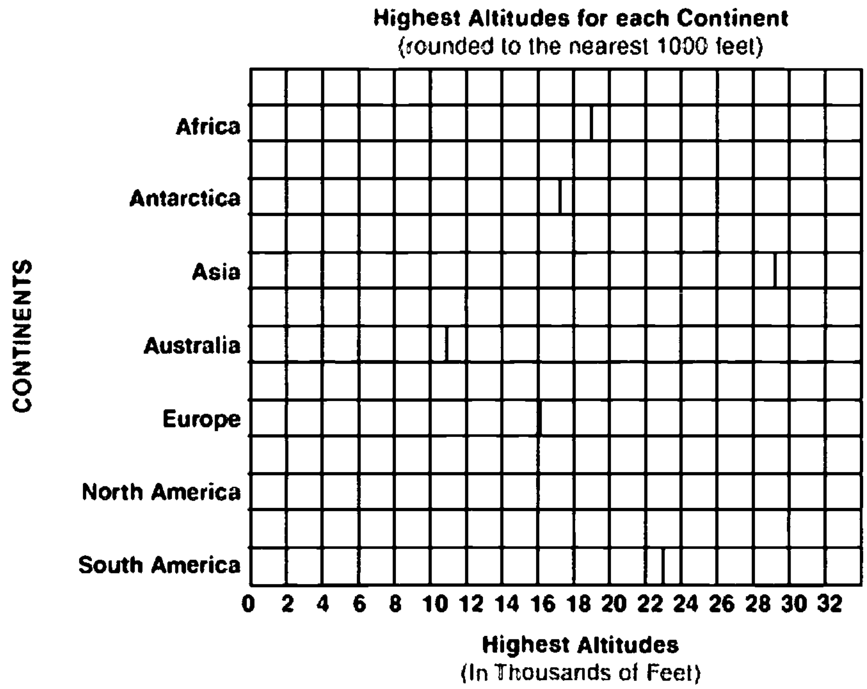
b. $410.00

c. $85.00

c. $82.00

Figure 2. Grade 8 practice test item from Minnesota's BST (Basic Skills Test), 1998.

Use the bar graph below to answer question 59.



59. **The highest altitude in the world is located on what continent?**

- **A.** South America
- **B.** Australia
- **C.** Africa
- **D.** Asia

Figure 3. Grade 8 released test item from the Missouri Assessment Program (MAP), 2002.

10 For the Shallwood Middle School Fun Night next month, 600 students voted for their favorite activity. The results and the costs associated with each activity are shown in the table below.

FAVORITE ACTIVITIES FOR FUN NIGHT

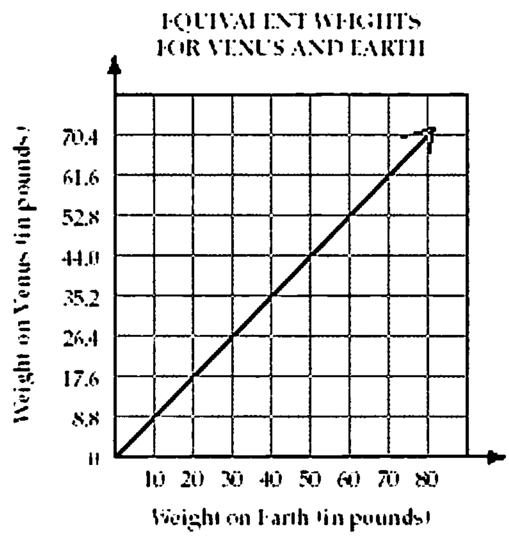
Favorite Activity	Percentage Who Voted	Cost (in dollars)
Playing music	21	250
Movies	10	30
Volleyball	15	10
Board games	2	60
Arcade games	25	200
Miniature golf	9	50
Free-throw shot	15	15
Face painting	3	10

Fun Night will have at least three activities, but no more than six activities. The committee can spend up to $300 on all the activities.

In the box below, write a recommendation to the committee about which activities to select for Fun Night. To ensure good attendance, at least 50% of the total number of students must have voted for the combination of activities that you choose. Be sure to provide the work to support your recommendation with percentages and costs from the table.

Figure 4. Grade 8 released test item from the Florida Comprehensive Assessment Test (FCAT), 2003.

1 The graph below represents the equivalent weights, in pounds, of people on the planets Venus and Earth.



What is the weight of a person on Earth if his or her equivalent weight on Venus is 44 pounds?

A. 30 pounds

B. 40 pounds

C. 50 pounds

D. 60 pounds

Figure 5. Grade 7 sample test item from the Kansas Curricular Standards for Mathematics, 2001.

G7.S4.B2.A1.#1

The stem and leaf plot below represents the number of pages read by each student this week in the 3rd hour and 5th hour English classes.

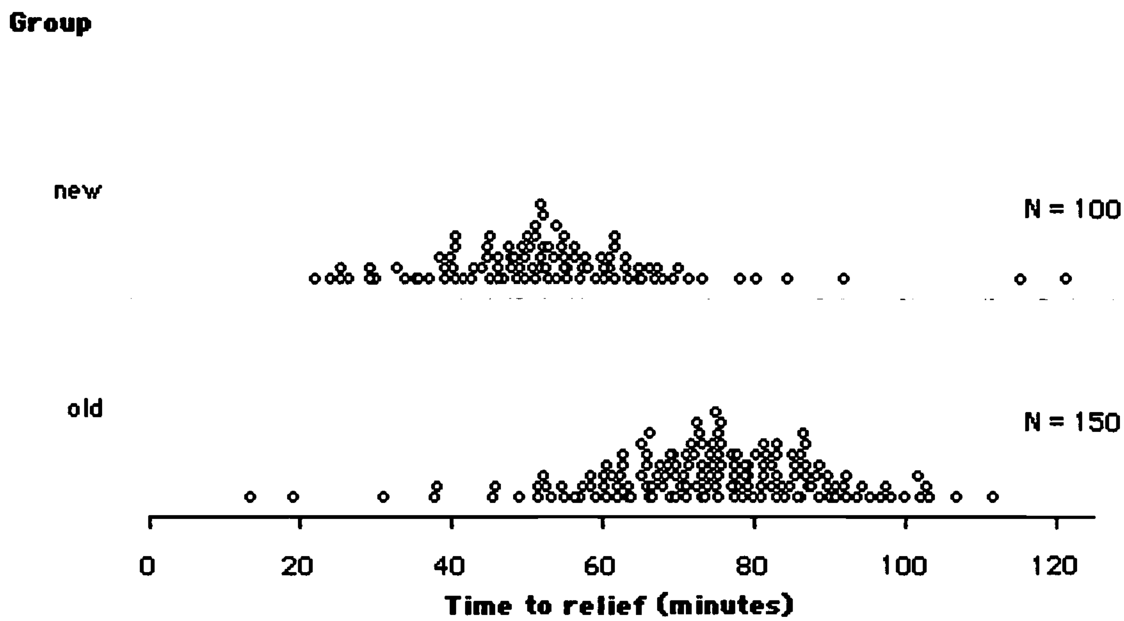
3rd hour	stem	5th hour
9 9 5 5 3 2	9	0 1 1 3
8 7 7 5 3 1	8	4 7
5 3 3	7	1 2 2 2 4 5 6
0	6	4 9
7 4	5	8 8
	4	2 5
9	3	7

Key:			
3	7		represents 73
	4	2	represents 42

Compare the box-and-whiskers plots of the data from these two classes. What inferences could be made about the number of pages read in each class.

Figure 6. Item under development, Tinkerplots project, 2003.

A drug company developed a new formula for their headache medication. To test the effectiveness of this new formula, they gave it to 100 people with headaches and timed how many minutes it took for the patient to report that the headache had gone. They compared the result from this test to previous results from 150 patients using the old formula under the exact same conditions. The results from both these clinical trials are shown below.



Based on these results, write a short summary of what these data say about the effectiveness of the new treatment compared to the old. The summary is for the drug company who wants to decide whether to start marketing the new formula.

Figure 7. Item under development, Tinkerplots project, 2003.

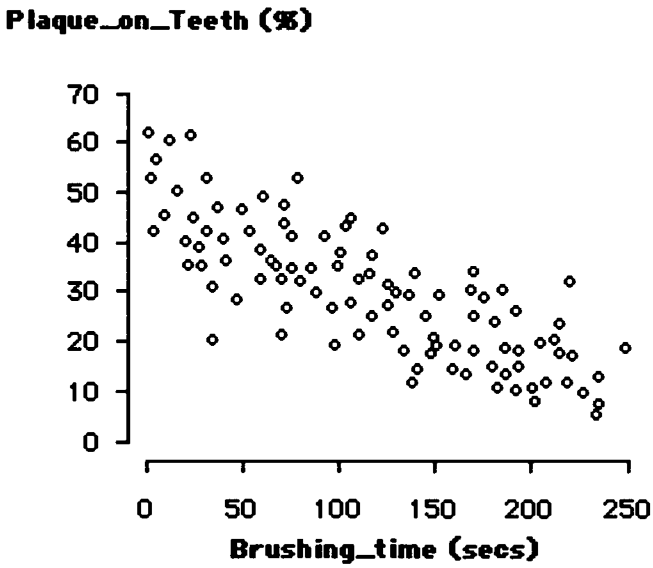
A tooth paste company did a study of how much brushing was required to remove most of the plaque that covers teeth. They studied 60 people. Each person brushed as they normally would, but were told after a certain number of seconds to stop brushing. An experimenter than determined the amount of plague remaining on that person's teeth.

The researchers reported the following findings:

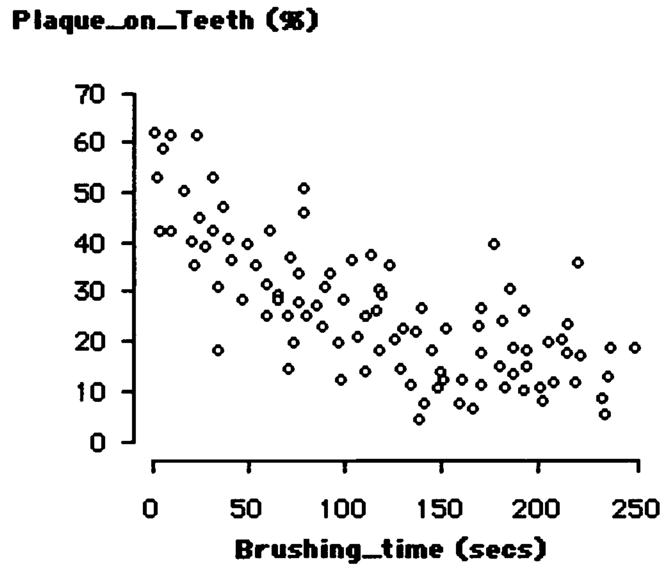
1) In the morning before brushing, plaque typically covers about 55% of the surface area of a person's teeth.
2) Up until about 120 seconds, the longer people brush the more plaque they remove.
3) After about 120 seconds, additional brushing does not appear to remove more plaque.

Below are four possible graphs of the data they collected. For each graph, say whether it agrees with these findings or not. If a graph doesn't agree with the findings, briefly explain why.

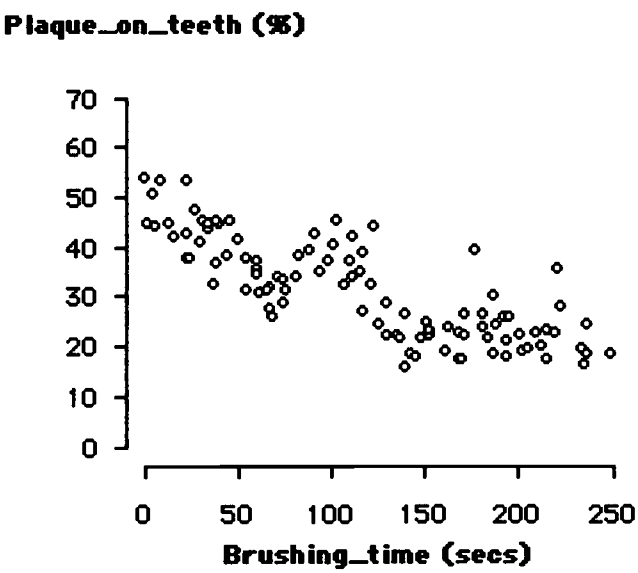
a.


Plaque_on_Teeth (%)
70
60
50
40
30
20
10
0
0
50
100
150
200
250
Brushing_time (secs)

b.


Plaque_on_Teeth (%)
70
60
50
40
30
20
10
0
0
50
100
150
200
250
Brushing_time (secs)

c.


Plaque_on_teeth (%)
70
60
50
40
30
20
10
0
0
50
100
150
200
250
Brushing_time (secs)

d.

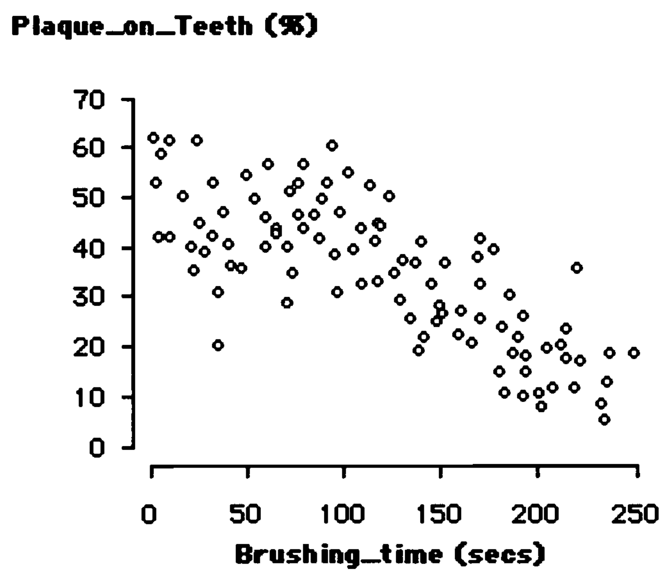
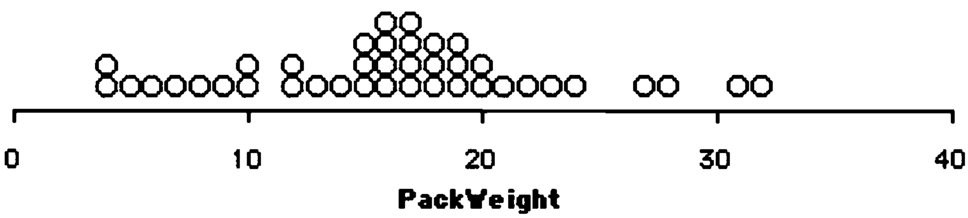

Plaque_on_Teeth (%)
70
60
50
40
30
20
10
0
0
50
100
150
200
250
Brushing_time (secs)

Figure 8. Item under development, Tinkerplots project, 2003.

As part of a campaign to get students to reduce the weight of their backpacks, middle school students set up a weighing station inside the main door of the school. They randomly selected students as they arrived at school, weighted their packs, and posted this information on a graph displayed on the wall. Data from the first 40 students they sampled are shown in the graph below.

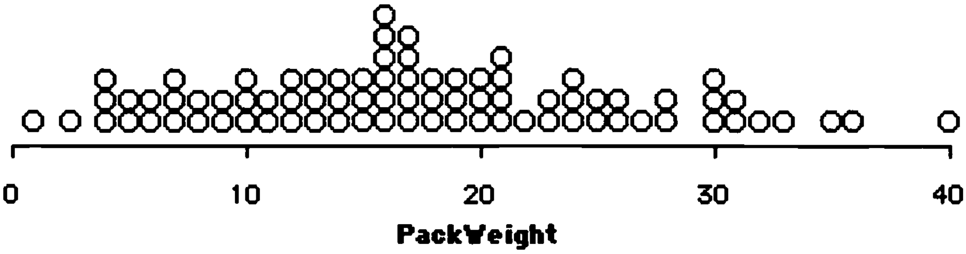


They randomly sampled another 40 students and added their data to the graph on the wall. Below are 4 possible graphs, with the new data shown in a different color. Which of the graphs do you think is most likely to be the actual graph they got after sampling a total of 80 students.

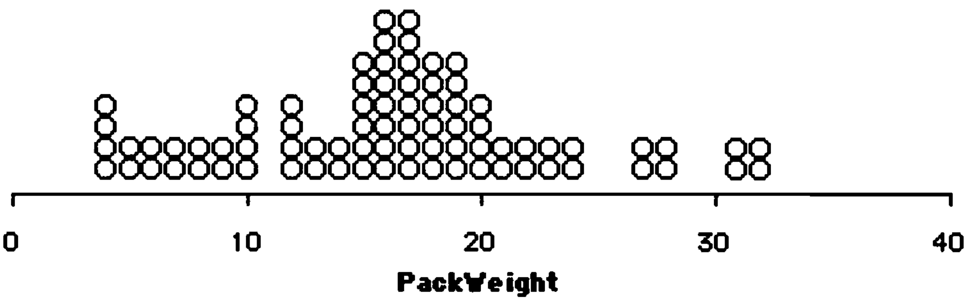
Graph ______

Explain your choice.

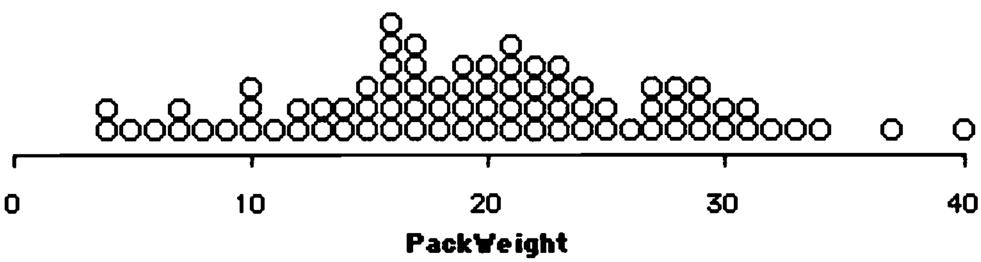
a.


0
10
20
30
40
PackWeight

b.


0
10
20
30
40
PackWeight

c.


0
10
20
30
40
PackWeight

d.

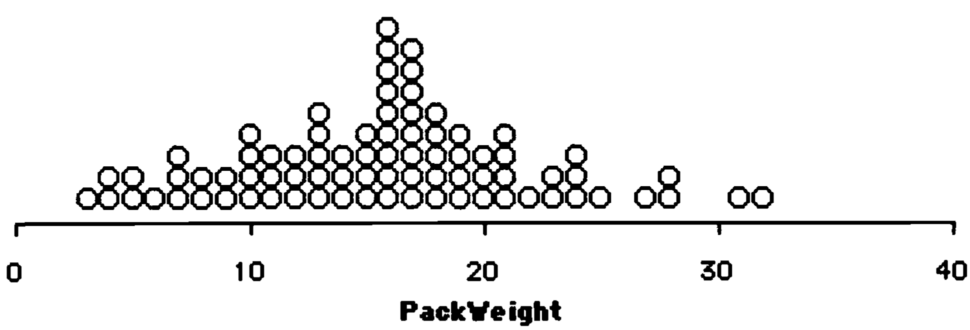

0
10
20
30
40
PackWeight

Table 1.

Table 1. Distribution of item types in high-stakes assessment exams.

State	Encode/ Decode	Other	%Encode/ Decode
>5 items			
Illinois	6	0	100.0
Minnesota	15	0	100.0
Mississippi	18	1	94.7
Ohio	13	1	92.9
Texas	11	1	91.7
Georgia	10	1	90.9
Utah	8	1	88.9
Virginia	8	1	88.9
Arkansas	7	1	87.5
Massachusetts	11	2	84.6
Florida	10	2	83.3
Connecticut	13	4	76.5
Tennessee	5	2	71.4
Michigan	7	3	70.0
New Hampshire	4	2	66.7
North Carolina	6	3	66.7
Kentucky	5	3	62.5
Washington	3	3	50.0
Colorado	3	4	42.9
South Carolina	3	4	42.9
Kansas	5	7	41.7
<6 items			
Alaska	2	0	100.0
California	1	0	100.0
Delaware	1	0	100.0
Indiana	3	0	100.0
Louisiana	2	0	100.0
New York	1	0	100.0
Oregon	5	0	100.0
Pennsylvania	1	0	100.0
Wyoming	2	0	100.0
Idaho	4	1	80.0
New Jersey	4	1	80.0
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