DOCUMENT RESUME

ED 380 503 TM 022 866

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TITLE	Using Trilinear Plots for NAEP State Data. Program Statistics Research. Technical Report. No. 94-6.
INSTITUTION	Educational Testing Service, Princeton, NJ. Program Statistics Research Project.
SPONS AGENCY	National Center for Education Statistics (ED), Washington, DC.
REPORT NO	ETS-RR-94-59
PUB DATE	94
CONTRACT	R99B40013
NOTE	40p.
PUB TYPE	Reports - Evaluative/Feasibility (142)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Charts; Demography; Educational Assessment; *Educational Trends; Elementary Secondary Education; *Mathematics Achievement; National Surveys; Performance; *Research Reports; Trend Analysis
IDENTIFIERS	*Trial State Assessments (NAEP); *Trilinear Plots

ABSTRACT

Understanding the distribution of achievement levels of students' performance on the National Assessment of Educational Progress (NAEP) is aided through the use of the trilinear chart. This chart is described and its use illustrated with data from the 1992 state NAEP mathematics assessment. The trilinear chart is used to portray three variables simultaneously expressed in the form of components of a total. It is drawn like an equilateral triangle, each side of which is calibrated in equal percentage divisions from 0 to 100. It is shown that one can see readily the trends in performance for different demographic groups for all of the 44 participating jurisdictions simultaneously. Fifteen displays illustrate the analyses and portray some trilinear charts. (Contains 6 references.) (Author/SLD)

RR-94-59

Using Trilinear Plots For NAEP State Data

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Educational Testing Service

ETS ®

PROGRAM
STATISTICS
RESEARCH

Technical Report No. 94-6

Educational Testing Service
Princeton, New Jersey 08541

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Using Trilinear Plots For NAEP State Data[1]

Howard Wainer
Educational Testing Service

Abstract

Understanding the distribution of achievement levels of students' performance on NAEP is aided through the use of the trilinear chart. This chart is described and its use illustrated with data from the 1992 state NAEP mathematics assessment. It is shown that one can see readily the trends in performance for different demographic groups for all of the 44 participating jurisdictions simultaneously.

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[1] This research was supported by contract number R999B40013 from the National Center for Education Statistics to the Educational Testing Service, Howard Wainer, Principal Investigator. I am pleased to be able to acknowledge this help. In addition I am grateful for the advice and comments made on these charts by John Mazzeo and Paul Barton, which has led to some improvements.

Using Trilinear Plots For NAEP State Data

Introduction

Student performance on the tests of the National Assessment of Educational Progress (NAEP) has been characterized through a formal judgmental procedure into four levels: Advanced, Proficient, Basic, and Below Basic. Although the definitions of exactly what kinds of proficiencies constitute each level vary by age and subject matter, these levels are now in use in the math and verbal assessments. Moreover, current plans anticipate that they will eventually permeate all of the NAEP testing areas.

Because these performance levels are considered important for a variety of policy decisions and as a criterion based measure of school effectiveness, many tables are produced and printed that report the percentage of children that score in each of these categories for each NAEP jurisdiction. These tables are produced for each test separately for each of many demographic variables (e.g., ethnicity, sex, community type, parental education). A sample table is shown as display 1 (Table 1.4 from *1992 NAEP Trial State Assessment*)

Insert Display 1 about here

This table is complete and allows the easy extraction of any state's data, but aside from providing the National mean scores, it does not yield any intuitive view of the distribution of performance across all of the states. Such a view is important for example, in making comparisons among various demographic subgroups. It is toward providing such an effective display that this report is aimed.

Data Structure

Making plots of the average score for each state is an easy graphical task; stem-and-leaf plots (Wainer, 1994) work very well indeed. The more difficult design problem is displaying the four numbers that characterize the percentage of students who are at or beyond each of the achievement levels. Four numbers usually require a four dimensional display. This is often at odds with our very Euclidean perceptions. But are these data really four dimensional? Since the four achievement levels are mutually exclusive and exhaustive, the four numbers must sum to 100%. Thus given any three of the numbers we know the fourth exactly. Data that have this character are usually called a 'probability simplex' and a three dimensional display can completely display all four numbers. One such display is a tetrahedron in which each of the four apexes corresponds to 100% of a single achievement level. Each edge corresponds to everyone being at either of the two apexes that form the ends of that edge. Each face corresponds to everyone being at one of the three levels whose apexes form the three corners of that face. Any point that lies in the interior of the tetrahedron is a mixture of the four levels, the proportions of that mixture are measured by the distance of the point from the four apexes. Thus the full four variable problem has a graphical solution, that involves each state being a single point in 3-space. Such plots are currently in use for some applications (see Ramsay, 1993), but require either building a 3-dimensional physical model or using motion on a computer screen to simulate 3-dimensions. A graph that can be plotted on a piece of paper would have far greater usefulness.

A 2-dimensional graph would be easy if we could somehow reduce the number of achievement levels to three without losing too much information. Sadly for the enterprise of American education, but happily for graphical display, the level "Advanced" is practically empty. From Display 1 we can see that in no state are there more than 5% of the pupils at this high level, with the national average at 3%. In Display 2 is a plot that shows the percentages of 4th, 8th and 12th graders that performed at the advanced level in mathematics in the 1990 assessment. It is clear that for most purposes very little information would be lost if we combine Advanced and Proficient into a single category. If we do this we have a much more practically tractable display problem.

Insert Display 2 about here

A Trilinear Plot

With only three variables that always sum to 100% we have reduced the display problem to one that can be managed on a single face of the tetrahedron described earlier. Such a display has been called a "Trilinear chart" (Schmid & Schmid, 1978) and has enjoyed some successful applications (for example, Coleman (1961, p. 14), and more recently Upton (1994) in a splendid portrayal of the changes taking place in the British Parliamentary elections). The trilinear chart is used to portray simultaneously three variables expressed in the form of components of a total. "The trilinear chart is drawn in the form of an equilateral triangle, each side of which is calibrated in equal percentage divisions from 0 to 100. The rulings are projected across the chart parallel to the sides in the manner of coordinates" (Schmid & Schmid, 1978, p. 150). Some of the essential characteristics of a trilinear chart are shown in Display 3. The components are labeled normal to their associated axes which run from each apex to the mid-point of the opposite baseline.

Insert Display 3 about here

Some examples

While it is certainly true that the trilinear chart can naturally accommodate the individual state achievement level data, can it illuminate those data in a way that is currently either impossible or difficult? While its format suits the data perfectly, it has two counts against it. First, a fully explicated version (as in Display 3) is so full of axes and labels that there is hardly any room left for the data and their associated labels.

Second, it is not a commonly familiar display and so any prospective use will require some training for the reader. This may limit its applicability to a more technical audience.

We can attempt to deal with the first problem by simplifying the display somewhat, removing many of the grid lines and use the display to show broad structures rather than allow the extraction of details (which are better done with tables in most cases anyway). The second problem is an empirical one. How much training is necessary to allow a naive reader to understand data presented as a trilinear chart?

In Display 4 is a trilinear chart that shows the performance of the U.S. and two jurisdictions, Iowa and the Virgin Islands, on the 1992 8th grade NAEP State Mathematics Assessment. The arrows springing from each jurisdiction intersecting perpendicular to the three axes show how the points should be interpreted. 37% of Iowa's students performed at the 'Advanced or Proficient' level, compared to only 1% of those from the Virgin Islands and 23% for the nation as a whole. 44% of Iowa's students were at the Basic level compared to 12% in the Virgin Islands. Last, only 19% of Iowan's were 'Below Basic' compared to 87% in the Virgin Islands. Obviously these are two extreme points, but they serve to illustrate how to read the chart. Intuition is aided by noting the direction and distance one must traverse in moving from the Virgin Islands to Iowa. In geographic terms, moving east is good, moving north is better; in general any jurisdiction that is northeast of another dominates the latter in both "Basic" and "Proficient+Advanced" categories.

Insert Display 4 about here

Showing two points in a comprehensible way is no trick. How well does this display method allow us to look at large quantities of data? Shown in Display 5 are all 44 of the participating jurisdictions (41 states, Guam, the Virgin Islands and the District of Columbia), as well as small squares representing the four aggregate regions of the country as well as an open circle representing the national average. The general structure is clear, although it is difficult to identify any particular jurisdiction. As we can see all of the points range near a diagonal line with a slope of about 30°. None of the points fall into the top segment labeled 'Proficient & Advanced'. What does this mean?

Insert Display 5 about here

In Display 6 we have simplified the picture somewhat by omitting portions of the axes lines. In so doing we have formed and labeled three tridants (surely not quadrants). Any jurisdiction that falls into one of these tridants has that tridant as its modal level. Thus, for example, Iowa, Minnesota and North Dakota have more 8th graders at the Basic level than at either of the other two. Whereas Guam, Mississippi and Louisiana, have more 8th graders at the 'Below Basic' level than any other. It is discouraging to note that no jurisdiction's point falls into the 'Proficient and Advanced' sector.

Insert Display 6 about here

We have seen how we can look at all three levels of achievement for all of the NAEP jurisdictions simultaneously. Can we use this same tool to compare various subgroups? The answer is "certainly," but how can this be done most efficaciously? In Displays 7, 8, 9, and 10 are trilinear plots for all of the NAEP jurisdictions with large enough samples to yield estimates of acceptable accuracy for the four most common ethnic groups: Blacks, Hispanics, Whites, and Asian/Pacific Islanders. One way to display these is, as we have done, arrayed over a page. The eye can then wander around the page and see the profound differences among the ethnic groups. We see the obvious outcome of Black and Hispanic students doing poorly; Whites and Asians doing considerably better. We can see that there is no overlap between the distributions of whites and blacks; that the state in which blacks do best still performs worse than the state that whites do worst. The plot for Asian/Pacific Islanders shows us many things, two among them are: only ten jurisdictions had enough Asians to yield any estimate at all, and that four states (Maryland, Connecticut, New Jersey and Texas) had Proficient and Advanced' as their modal level.

Insert Display 7, 8, 9, 10 and 11 about here

Another way to compare the performances of the various ethnic groups is to plot them all together on the same set of axes. This is useful when, as in the Black-White comparison, the distributions are non-overlapping. When this is not the case the resulting plot may become too busy. A dynamic alternative is to stack the plots one on top of the other on a computer screen (with only the top one visible) and switch from one to the next at the rate of perhaps one or two a second. The Phi-phenomenon takes over and all we see is a moving cloud of points within a fixed outer frame. A static alternative (Display 11) would be to substitute a suitably shaped and scaled oval for the cloud of points. In this version we can not only see the differences in location of the performance of the four ethnic groups represented, but also something of their variability. Note that The performance of Whites and Blacks seems to be more homogeneous than that exhibited by Hispanics and Asians.

Conclusions and expansions

Levels of Achievement are tabled for several other demographic variables besides ethnicity. Unlike ethnicity, some these variables can be thought of as causal. One such background variable is 'Parental education'. Can we use the trilinear plot to help us to understand the approximate size of the causal effect of such a variable? To explore this we can plot the points associated with children whose parents did not graduate from high school (Display 12) and again for those whose parents are college graduates (Display 13). Viewed side-by-side we can see that there is very little over-lap between the two distributions. But to see the size of the effect of the variable "parents' education" we must connect the points representing each jurisdiction. The size of the line joining them is a measure of the size of the effect of the variable "parents' education."

Insert Display 12, 13, 14, and 15 about here

In Display 14 is an attempt to do this with only ten states. It is too confusing to be of much help, although we do see the expected effect that as the bottom point shifts to the right the slope of the connecting line gets steeper. This isn't surprising. It merely shows graphically that in states in which a greater proportion of children from relatively more poorly educated families do rather well, those children from the same state from better educated families do better still. While this is not a surprising result (in fact it is almost tautological), it is reassuring to see that even in as over-busy a display as this, it jumps out at us.

One simplification that may be of help is to utilize this display technology within a dynamic framework. Most users of the display have particular interest in a specific jurisdiction. Thus we can simplify the display considerably by omitting all extraneous graph lines and plotting only the end points for each jurisdiction, keeping visually separate the symbols for the two groups of children from homes with vastly different backgrounds in schooling. Then connect only the points for the jurisdictions of interest. In Display 15 is one version of this. The is a line for New Jersey and another, principally for comparative purposes, for the entire country. The immediate message we get is that New Jersey's children on both extremes of this spectrum perform among the top 8 or 10 jurisdictions.

Simplifying the display by removing some of its explanatory elements is a reasonable thing to do once the reader becomes accustomed to its character. A graph as full of help as the one pictured in Display 3 leaves little room for the data. An important consideration whenever an innovative graphical format is proposed must be the gains associated the new form versus the losses associated with moving away from the conventional display. Pie charts are used despite their flaws because they are a conventional and obvious metaphor. Trilinear plots are not in common use, and despite their obvious appropriateness in this application, they take some getting used to. It was our intention to provide some experience with the 13 variations and examples here so that the reader can gain experience and comfort with the format. Once this has occurred the display components that orient the naive viewer can be downplayed visually leaving more room for data. One obvious direction for increasing the richness of the data would be an expansion of Display 14 by deleting the points entirely and substituting jagged lines for each jurisdiction that connect the (now invisible) points associated with several levels of parental schooling. How many lines can be visually accommodated is an empirical question. But the tale told by such a single image, were it comprehensible, would be nothing less than a state-by-state depiction of the effect of parents' education on children's mathematics performance. Being able to do this in an accessible way seems a worthy goal.

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Display Captions

Display 1. Excerpt from Table 1.4 from *NAEP 1992: Mathematics Report Card for the Nation and the States* showing the percentage of public school children at each of the achievement levels for the 44 participating jurisdictions, four selected aggregates, as well as for the nation as a whole.

Display 2. A plot showing the relative percentages of 4th, 8th and 12th grade students in the 1990 Mathematics Assessment at each of the four achievement levels. It indicates that little information is lost by combining the category "Proficient" with that of "Advanced."

Display 3. A fully detailed description of a sample trilinear chart from Schmid & Schmid (1978).

Display 4. A sample trilinear chart showing the relative positions of Iowa, the Virgin Islands and the Nation on the 1992 NAEP State Mathematics Assessment.

Display 5. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment.

Display 6. A simplified trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment. On this version about half of the jurisdictions are explicitly identified and the principal tridants are graphically emphasized.

Display 7. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for Black students.

Display 8. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for Hispanic students.

Display 9. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for White students.

Display 10. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for Asian/Pacific Islander students.

Display 11. A schematic trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for all four ethnic groups.

Display 12. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for children whose parents did not graduate from high school.

Display 13. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for children whose parents were college graduates.

Display 14. A sample trilinear chart showing the relative positions of ten participating jurisdictions on the 1992 NAEP State Mathematics Assessment for children whose parents did not graduate from high school as well as for children whose parents were college graduates. The length of lines connecting these points indicate the size of the contribution that parental schooling has on children's performance on 8th grade mathematics.

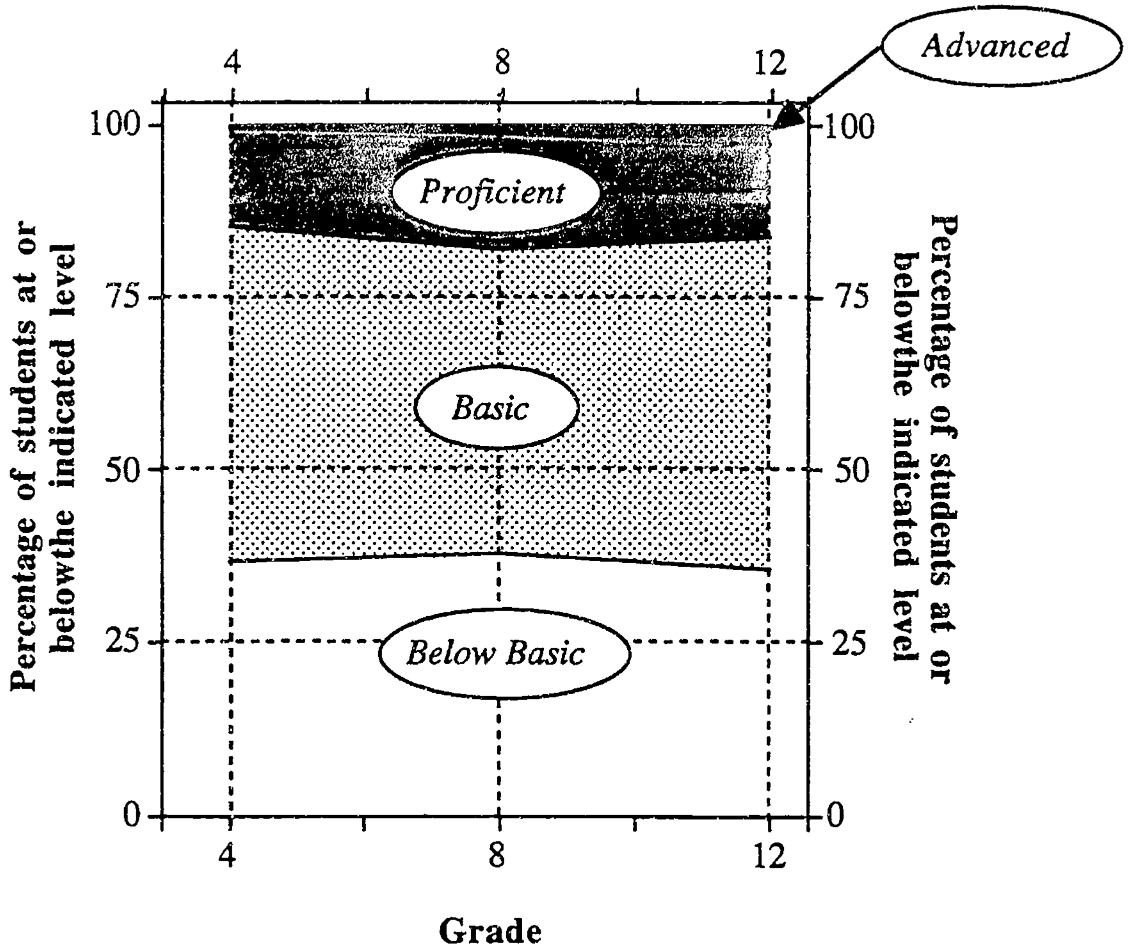
Display 15. A sample trilinear chart showing the relative positions of all participating jurisdictions on the 1992 NAEP State Mathematics Assessment for children whose parents did not graduate from high school as well as for children whose parents were college graduates. The gain associated with parental education is depicted explicitly for New Jersey by joining the two points for that state. It is also done for the nation as a whole to provide a measure of comparison.

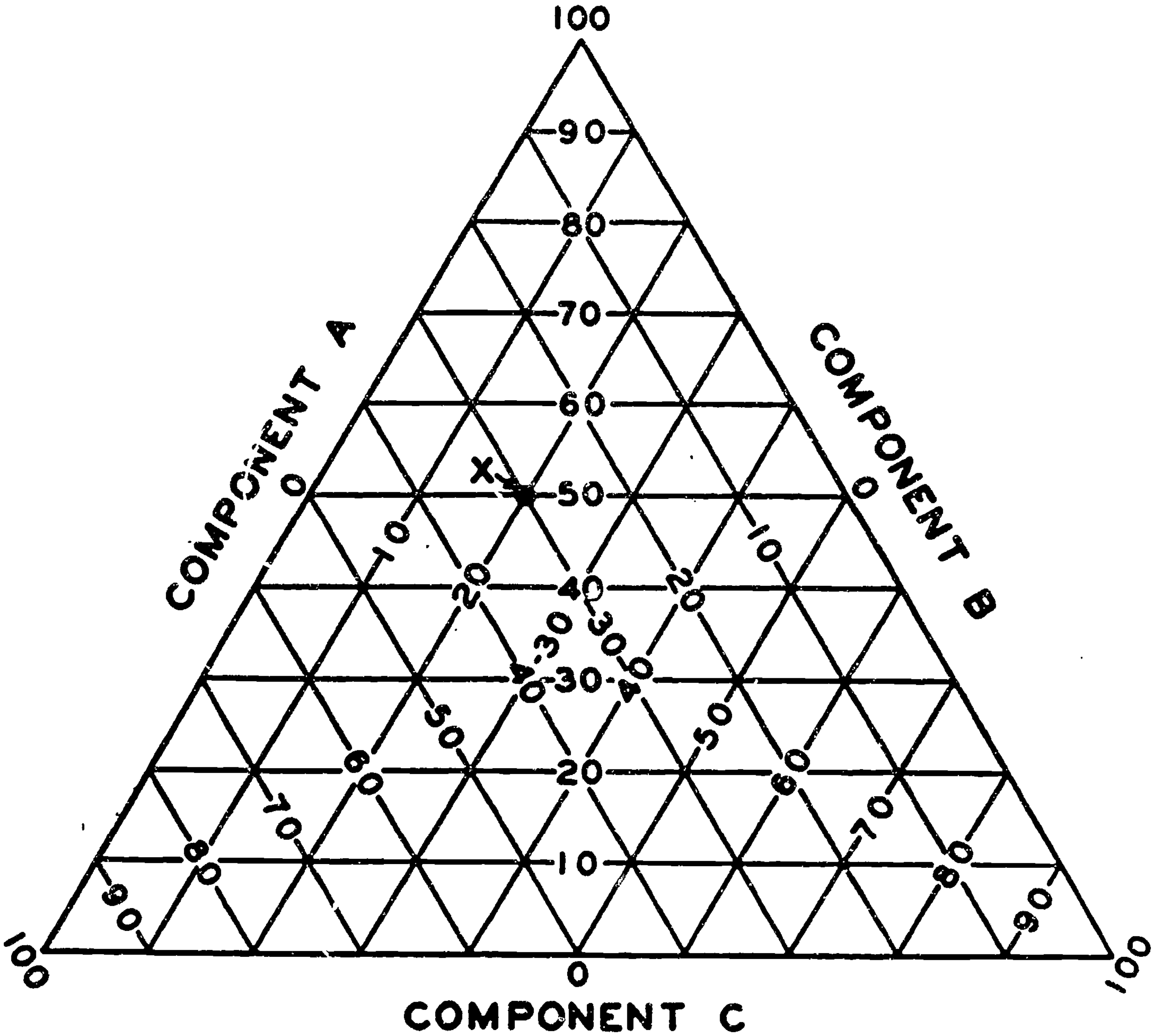
TABLE 14 | Overall Average Mathematics Proficiency and Achievement Levels

PUBLIC SCHOOLS	Grade 8 - 1992				
	Average Proficiency	Percentage of Students At or Above Advanced	Percentage of Students At or Above Proficient	Percentage of Students At or Above Basic	Percentage of Students Below Basic
NATION	266 (1.0)	3 (0.5)	23 (1.1)	61 (1.2)	39 (1.2)
Northeast	267 (3.0)	5 (1.4)	25 (3.0)	59 (3.9)	41 (3.9)
Southeast	258 (1.2)	1 (0.4)	16 (1.0)	53 (1.6)	47 (1.6)
Central	273 (2.2)	3 (0.7)	28 (3.0)	70 (2.8)	30 (2.8)
West	267 (2.1)	4 (1.1)	24 (2.1)	62 (2.7)	38 (2.7)
STATES					
Alabama	251 (1.7)	1 (0.3)	12 (1.1)	44 (2.0)	56 (2.0)
Arizona	265 (1.3)>	2 (0.4)	19 (1.4)	61 (1.8)>	39 (1.8)<
Arkansas	255 (1.2)	1 (0.3)	13 (1.0)	50 (1.7)	50 (1.7)
California	260 (1.7)	3 (0.7)	20 (1.4)	55 (2.0)	45 (2.0)
Colorado	272 (1.1)>	2 (0.5)	26 (1.3)>	69 (1.3)>	31 (1.3)<
Connecticut	273 (1.1)>	4 (0.8)	30 (1.1)>	69 (1.4)	31 (1.4)
Delaware	262 (1.0)	3 (0.4)	18 (1.1)	57 (1.2)	43 (1.2)
Dist. Columbia	234 (0.9)>	1 (0.2)	6 (1.0)	26 (1.3)>	74 (1.3)<
Florida	259 (1.5)	2 (0.4)	18 (1.3)	55 (1.9)	45 (1.9)
Georgia	259 (1.2)	1 (0.3)	16 (1.0)	53 (1.5)	47 (1.5)
Hawaii	257 (0.9)>>	2 (0.4)	16 (0.8)	51 (1.2)>>	49 (1.2)<<
Idaho	274 (0.8)>	3 (0.4)	27 (1.2)	73 (1.1)	27 (1.1)
Indiana	269 (1.2)	3 (0.4)	24 (1.3)	66 (1.5)	34 (1.5)
Iowa	283 (1.0)>>	5 (0.7)	37 (1.4)>	81 (1.2)>	19 (1.2)<
Kentucky	261 (1.1)>	2 (0.4)	17 (1.1)	57 (1.3)>	43 (1.3)<
Louisiana	249 (1.7)	1 (0.2)	10 (1.2)	42 (2.0)	58 (2.0)
Maine	278 (1.0)	4 (0.8)	37 (1.3)	77 (1.3)	23 (1.3)
Maryland	264 (1.3)	4 (0.8)	24 (1.3)	59 (1.5)	41 (1.5)
Massachusetts	272 (1.1)	3 (0.5)	28 (1.4)	68 (1.5)	32 (1.5)
Michigan	267 (1.4)	3 (0.5)	23 (1.7)	63 (1.6)	37 (1.6)
Minnesota	282 (1.0)>>	6 (0.7)>	37 (1.2)>>	77 (1.2)>	21 (1.2)<
Mississippi	246 (1.2)	0 (0.2)	8 (0.8)	34 (1.5)	62 (1.5)
Missouri	270 (1.2)	3 (0.4)	24 (1.3)	68 (1.6)	32 (1.6)
Nebraska	277 (1.1)	4 (0.5)	32 (1.9)	75 (1.2)	25 (1.2)
New Hampshire	278 (1.0)>>	3 (0.6)	30 (1.5)>	77 (1.0)>	23 (1.0)<
New Jersey	271 (1.6)	4 (0.6)	26 (1.4)	67 (1.8)	33 (1.8)
New Mexico	259 (0.9)>	1 (0.3)	14 (1.0)	54 (1.4)	46 (1.4)
New York	266 (2.1)	4 (0.8)	24 (1.6)>	62 (2.3)	38 (2.3)
North Carolina	258 (1.2)>>	1 (0.3)	15 (1.0)>	53 (1.5)>>	47 (1.5)<<
North Dakota	283 (1.2)	4 (0.6)	36 (1.7)	82 (1.3)	18 (1.3)
Ohio	267 (1.5)	2 (0.5)	22 (1.4)	64 (2.0)	36 (2.0)
Oklahoma	267 (1.2)>	2 (0.3)	21 (1.2)>	65 (2.0)	35 (2.0)
Pennsylvania	271 (1.5)	3 (0.7)	26 (1.5)	67 (1.7)	33 (1.7)
Rhode Island	265 (0.7)>>	2 (0.3)	20 (1.3)	62 (1.2)>>	38 (1.2)<<
South Carolina	260 (1.0)	2 (0.5)	18 (1.1)	53 (1.2)	47 (1.2)
Tennessee	258 (1.4)	1 (0.4)	15 (1.2)	53 (1.8)	47 (1.8)
Texas	264 (1.3)>	4 (0.6)	21 (1.4)>	58 (1.5)>	42 (1.5)<
Utah	274 (0.7)	3 (0.5)	27 (1.1)	72 (1.3)	28 (1.3)
Virginia	267 (1.2)	3 (0.5)	23 (1.2)	62 (1.6)	38 (1.6)
West Virginia	258 (1.0)	1 (0.2)	13 (0.9)	53 (1.5)	47 (1.5)
Wisconsin	277 (1.5)	4 (0.6)	32 (1.4)	76 (1.9)	24 (1.9)
Wyoming	274 (0.9)>	2 (0.5)	26 (1.0)	73 (1.3)	27 (1.3)
TERRITORIES					
Guam	234 (1.0)>	1 (0.2)	7 (0.7)	30 (1.4)	70 (1.4)
Virgin Islands	222 (1.1)>	0 (0.1)	1 (0.3)	13 (1.0)	87 (1.0)

Display 1

Results of the 1990 NAEP Mathematics Assessment

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COMPONENT A
COMPONENT B
COMPONENT C
X
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80
70
60
50
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10
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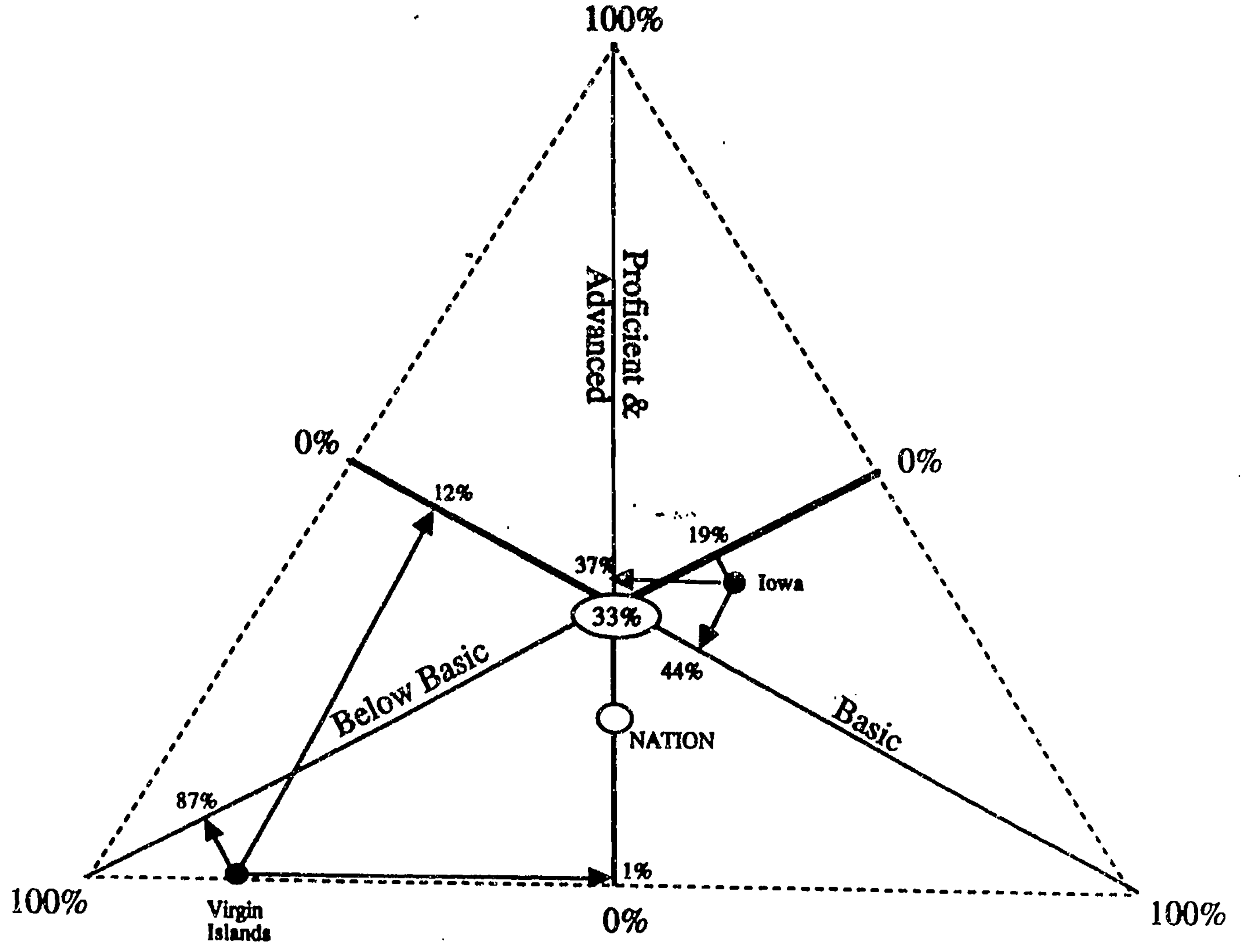
100

Display 3

1992 8th Grade NAEP State Mathematics Assessment



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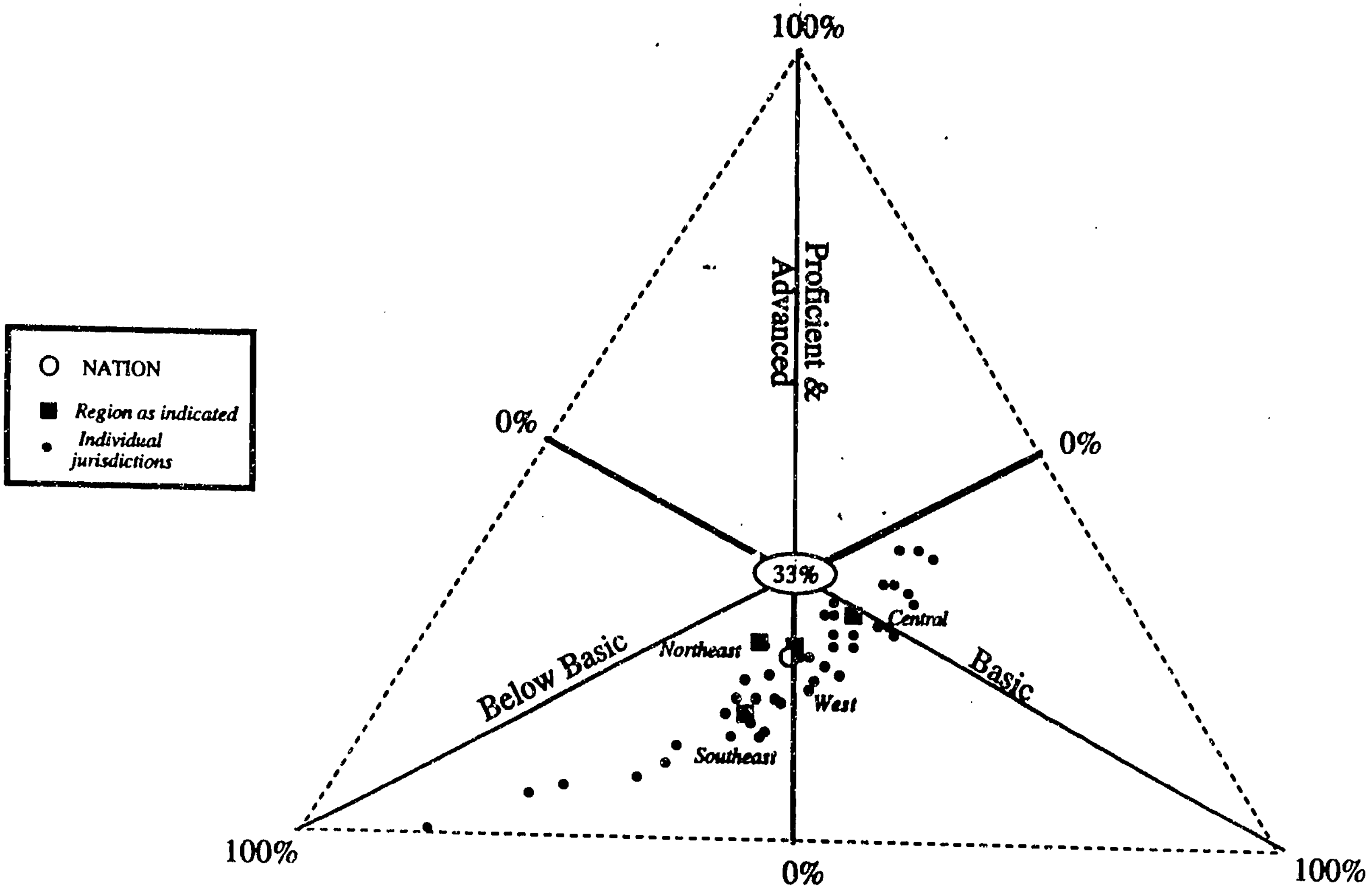
1992 8th Grade NAEP State Mathematics Assessment



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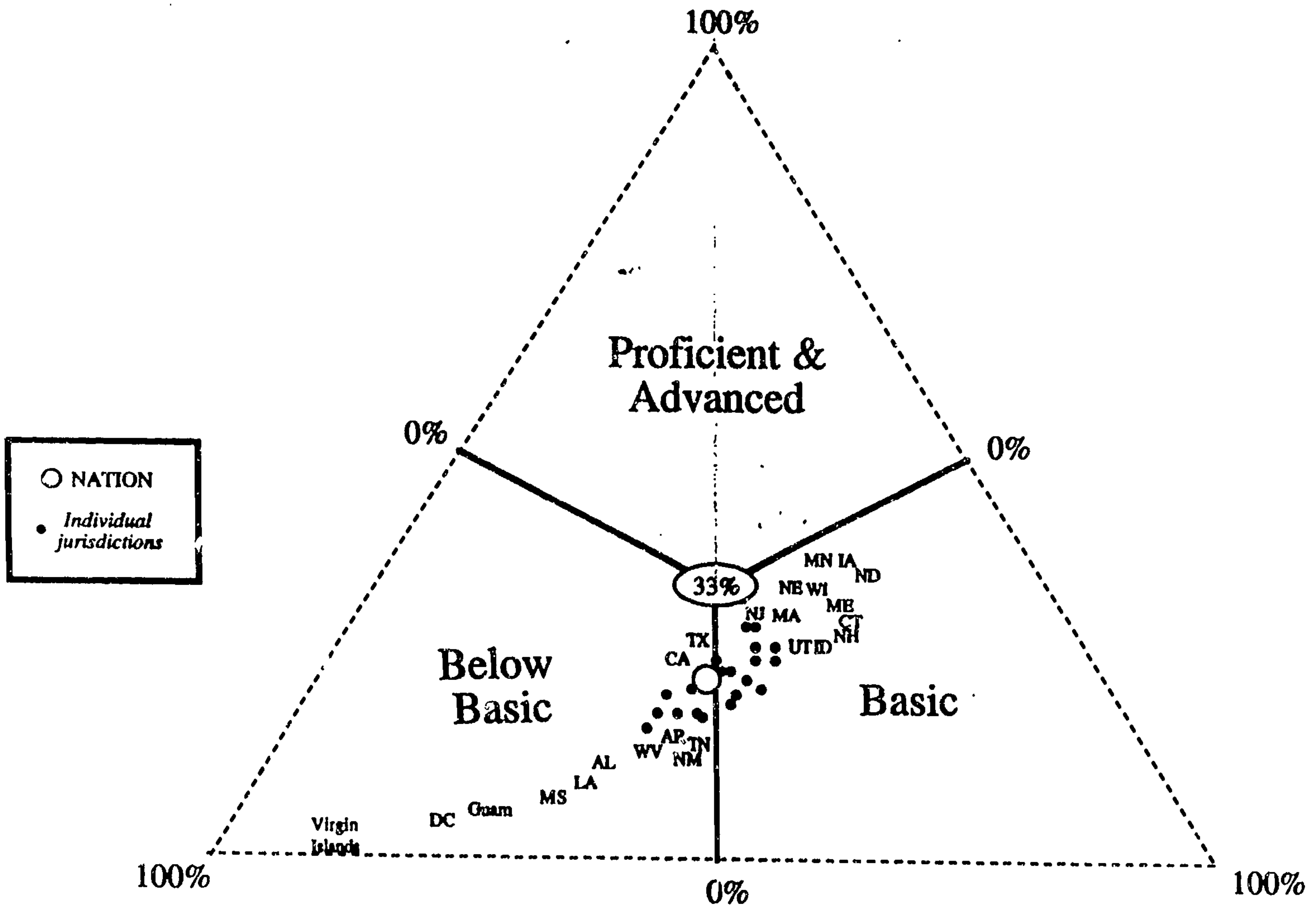
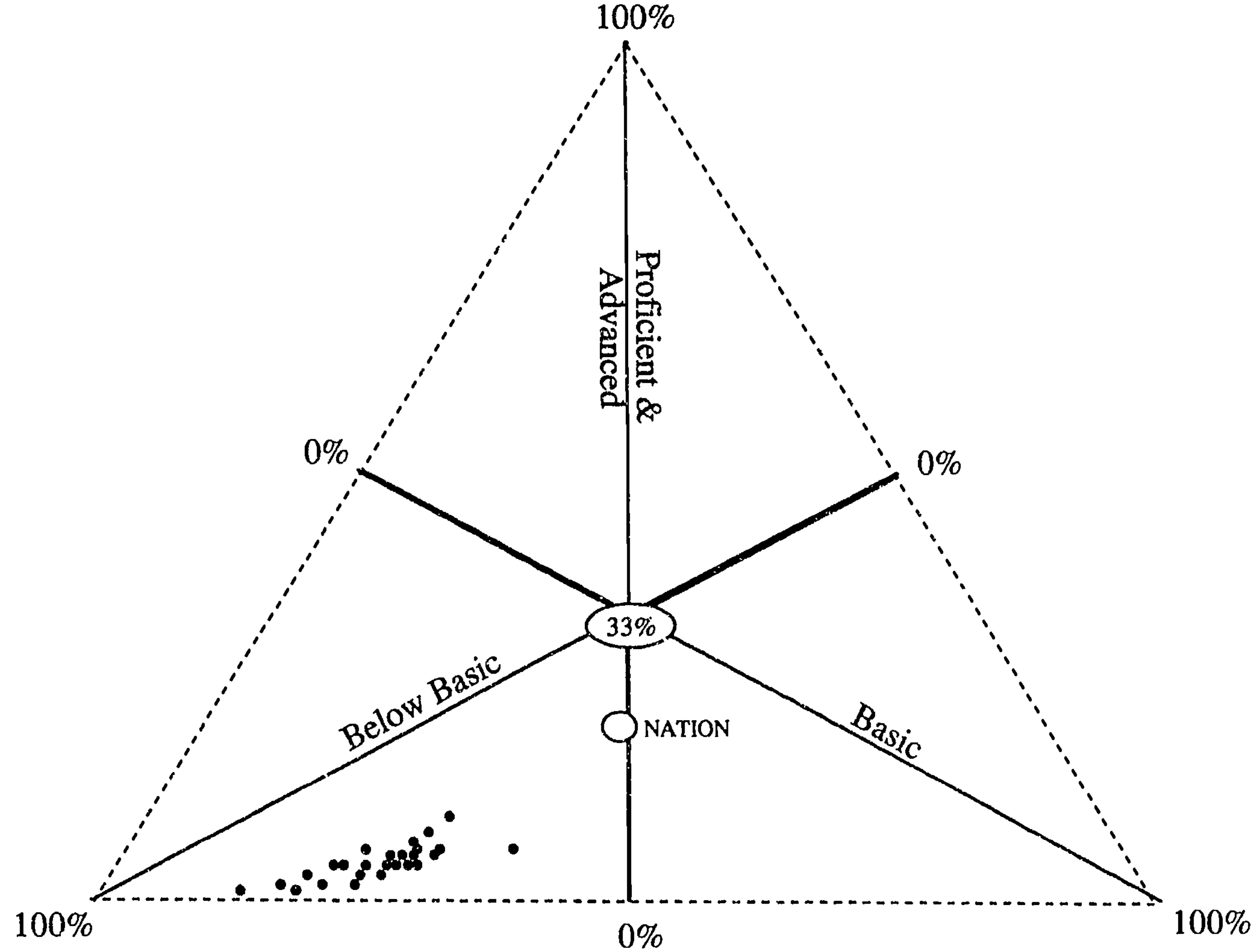


Display 6

1992 8th Grade NAEP State Mathematics Assessment for Black Students



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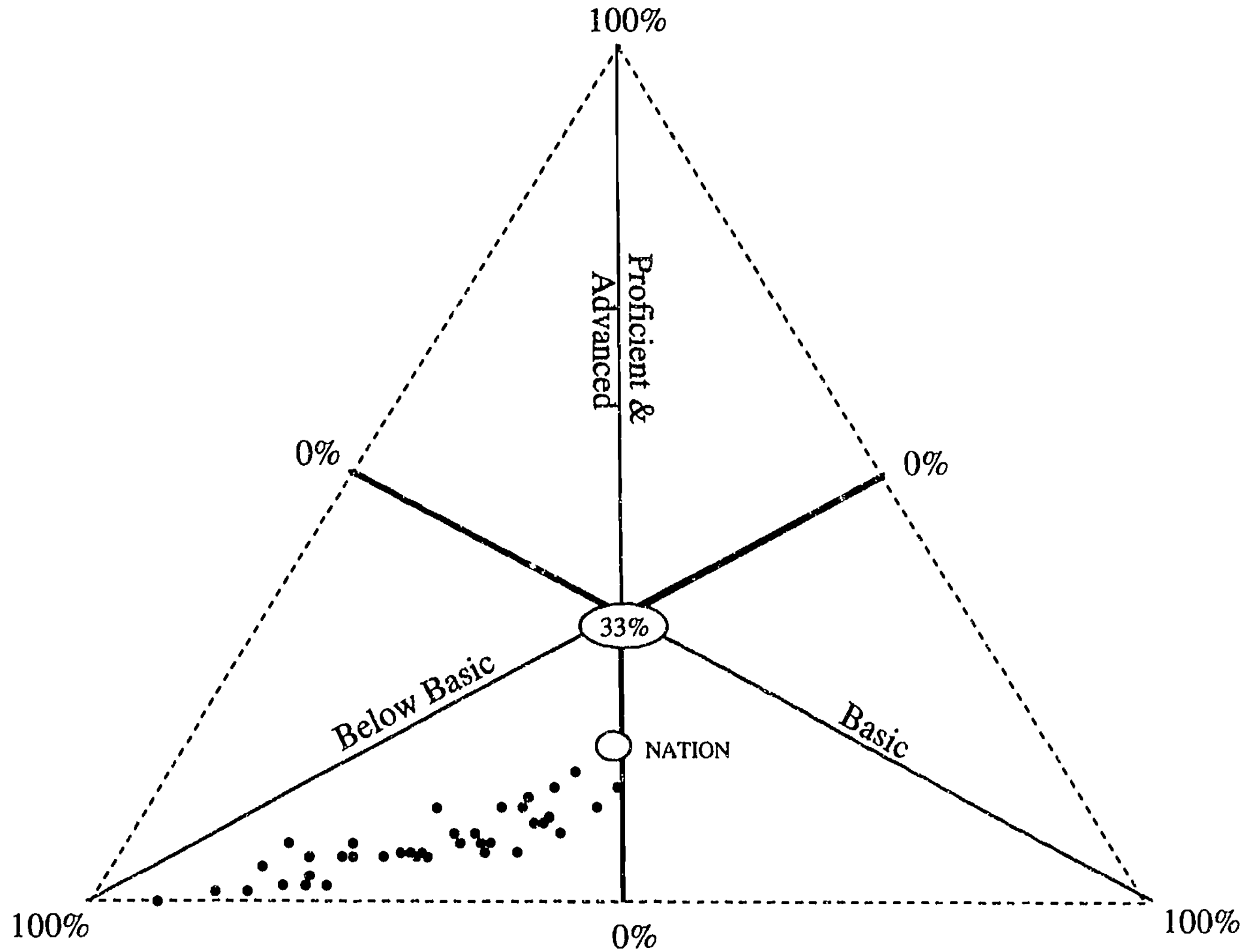
1992 8th Grade NAEP State Mathematics Assessment for Hispanic Students



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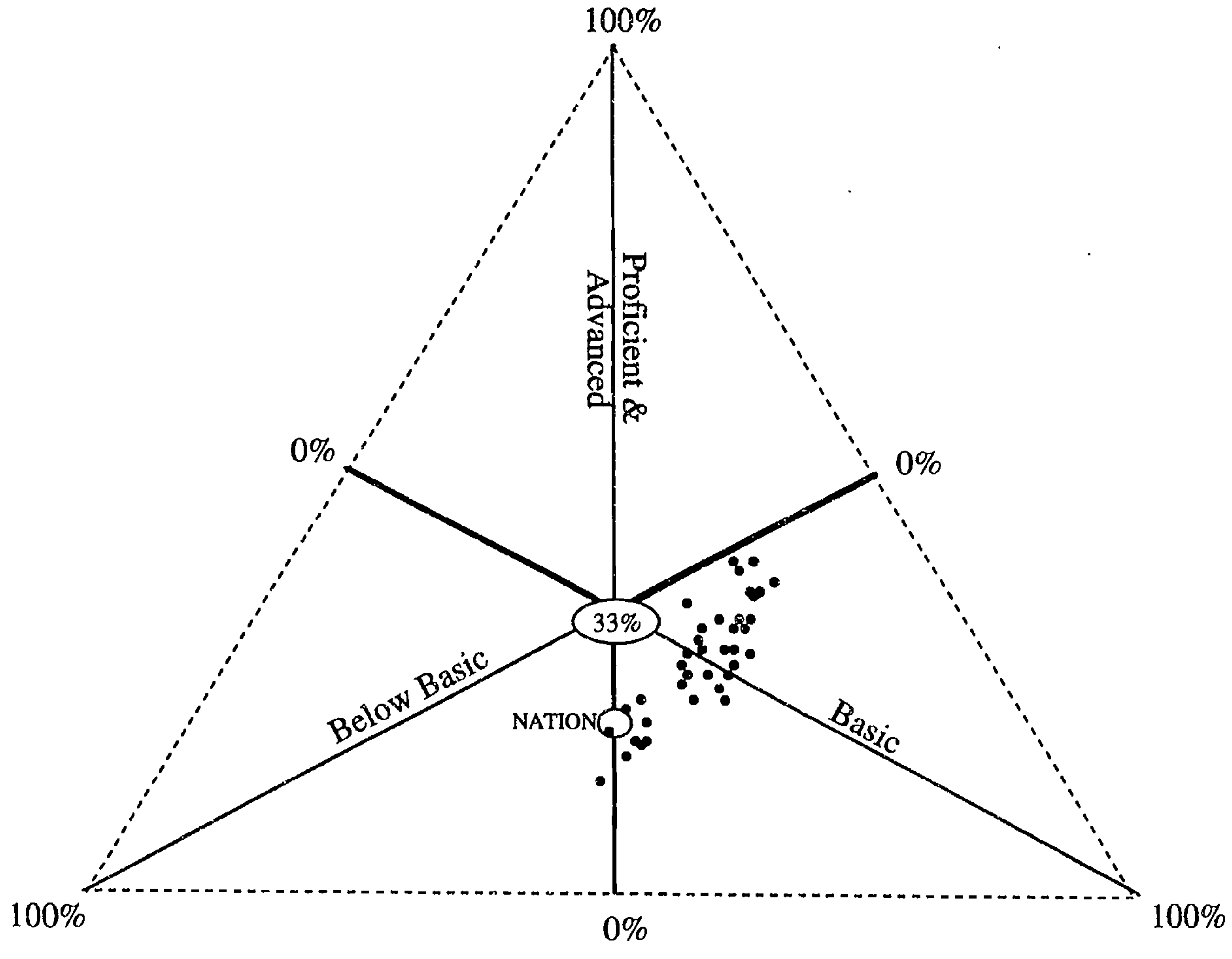
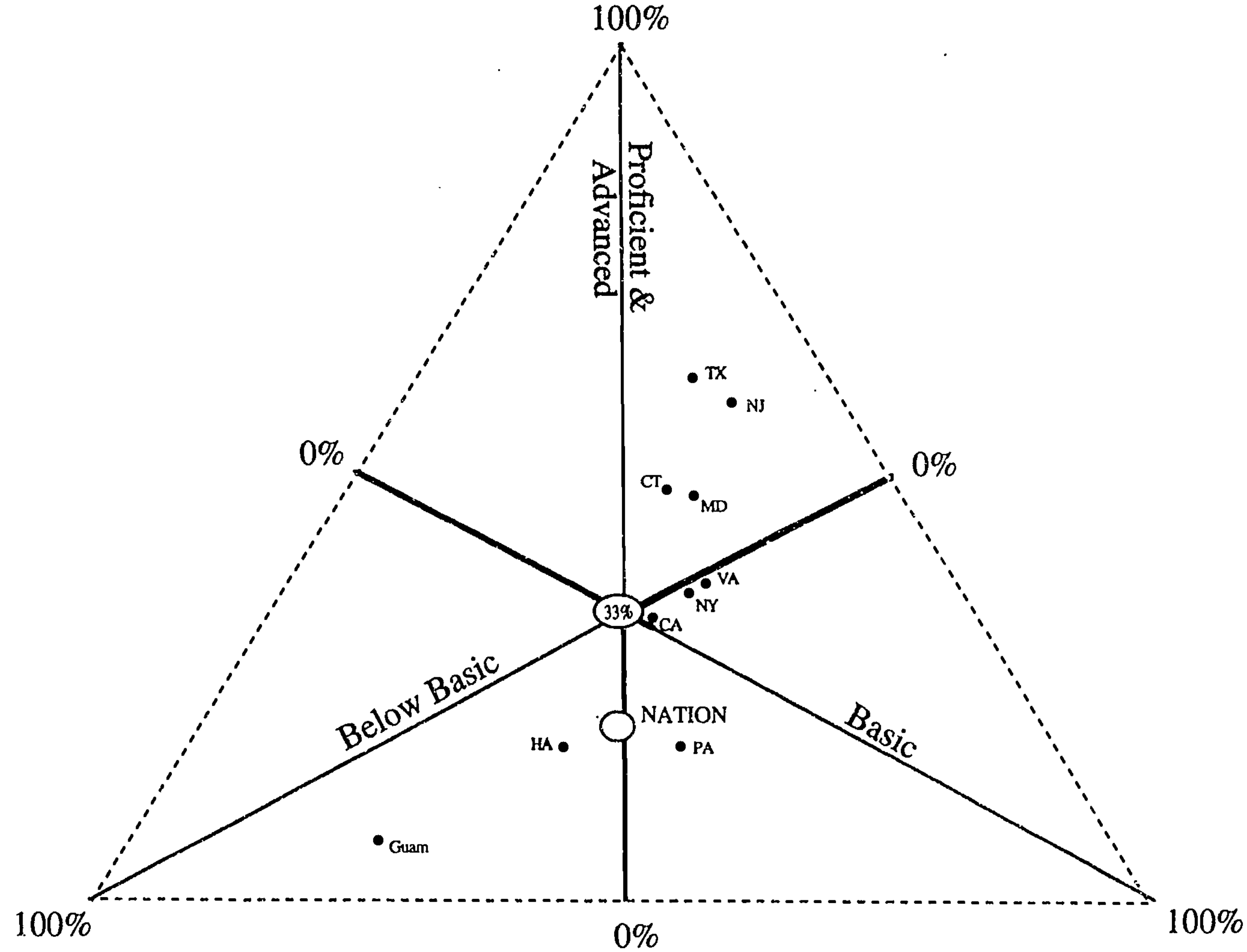
1992 8th Grade NAEP State Mathematics Assessment for White Students



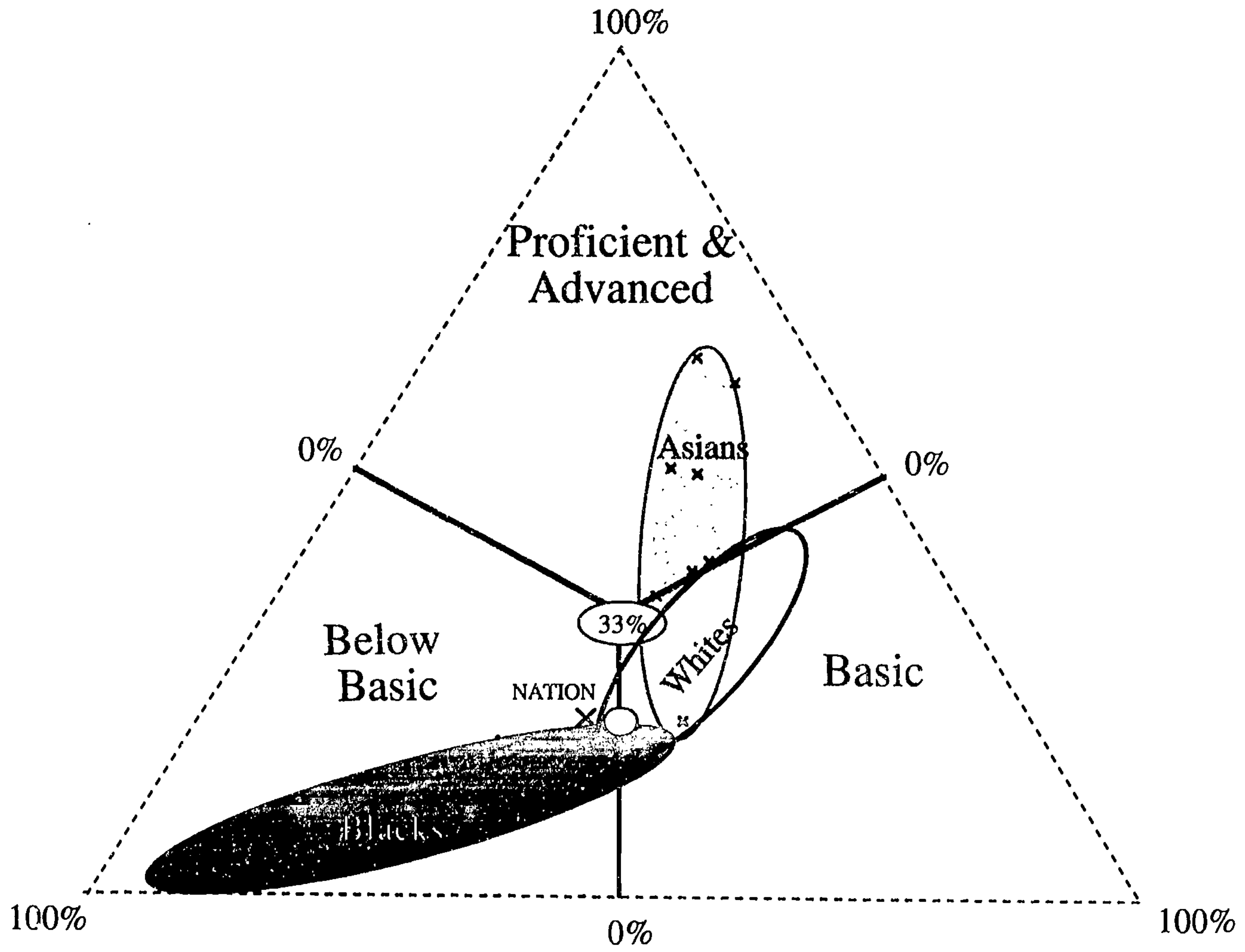
Display 9

1992 8th Grade NAEP State Mathematics Assessment for Asian/ Pacific Islander Students



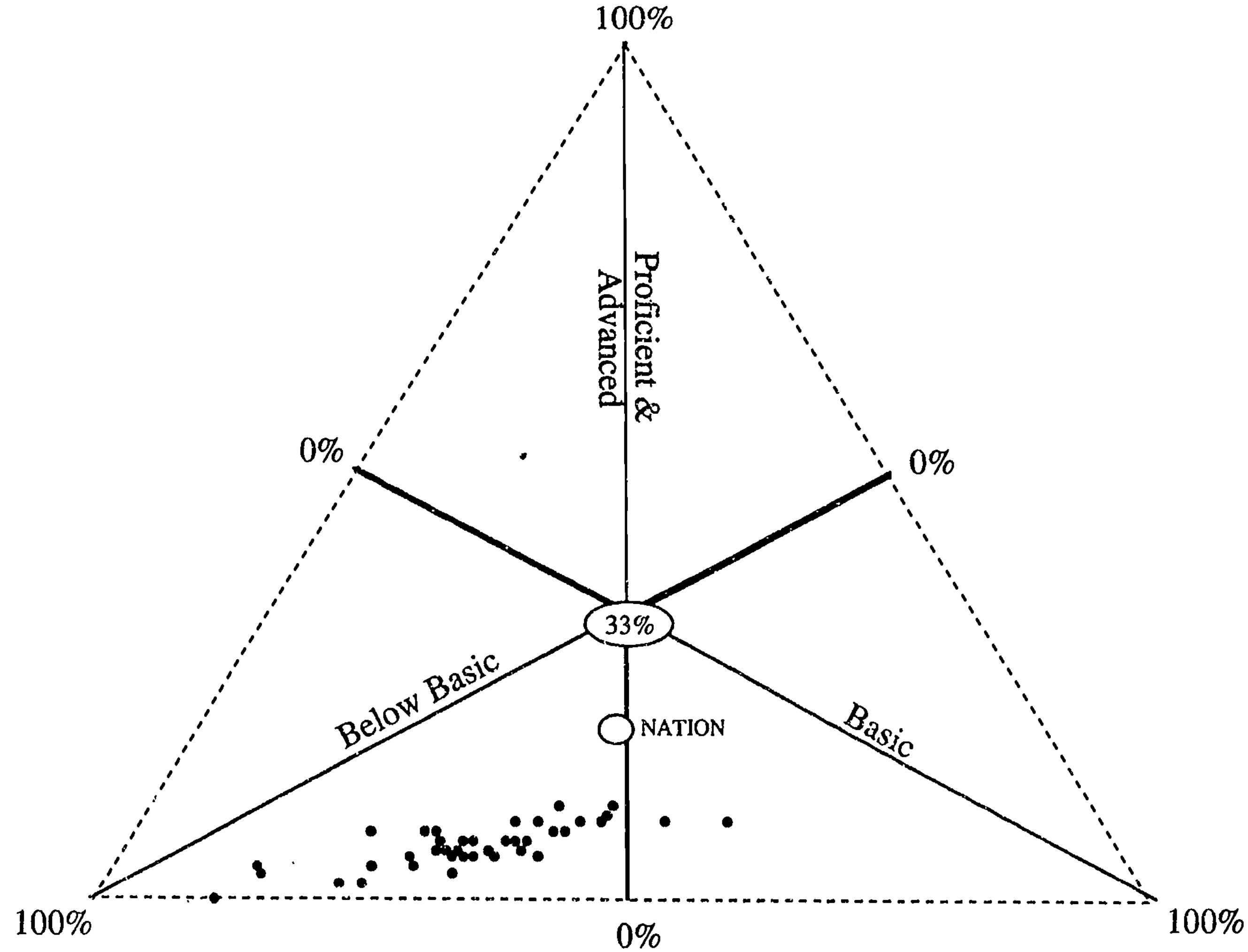
Display 10

1992 8th Grade NAEP State Mathematics Assessment



Display 11

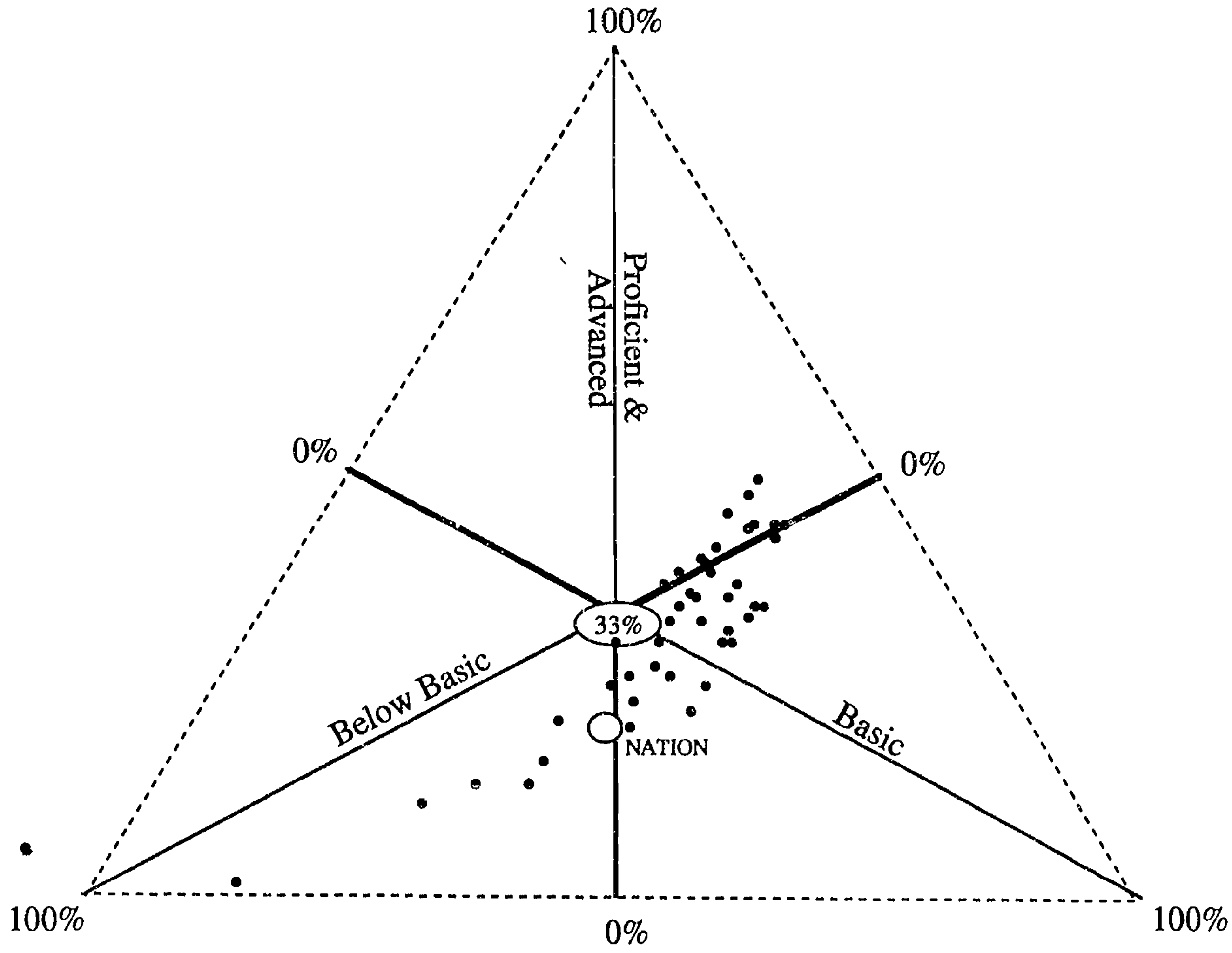
1992 8th Grade NAEP State Mathematics Assessment for Children Whose Parents did not complete High School



Display 12

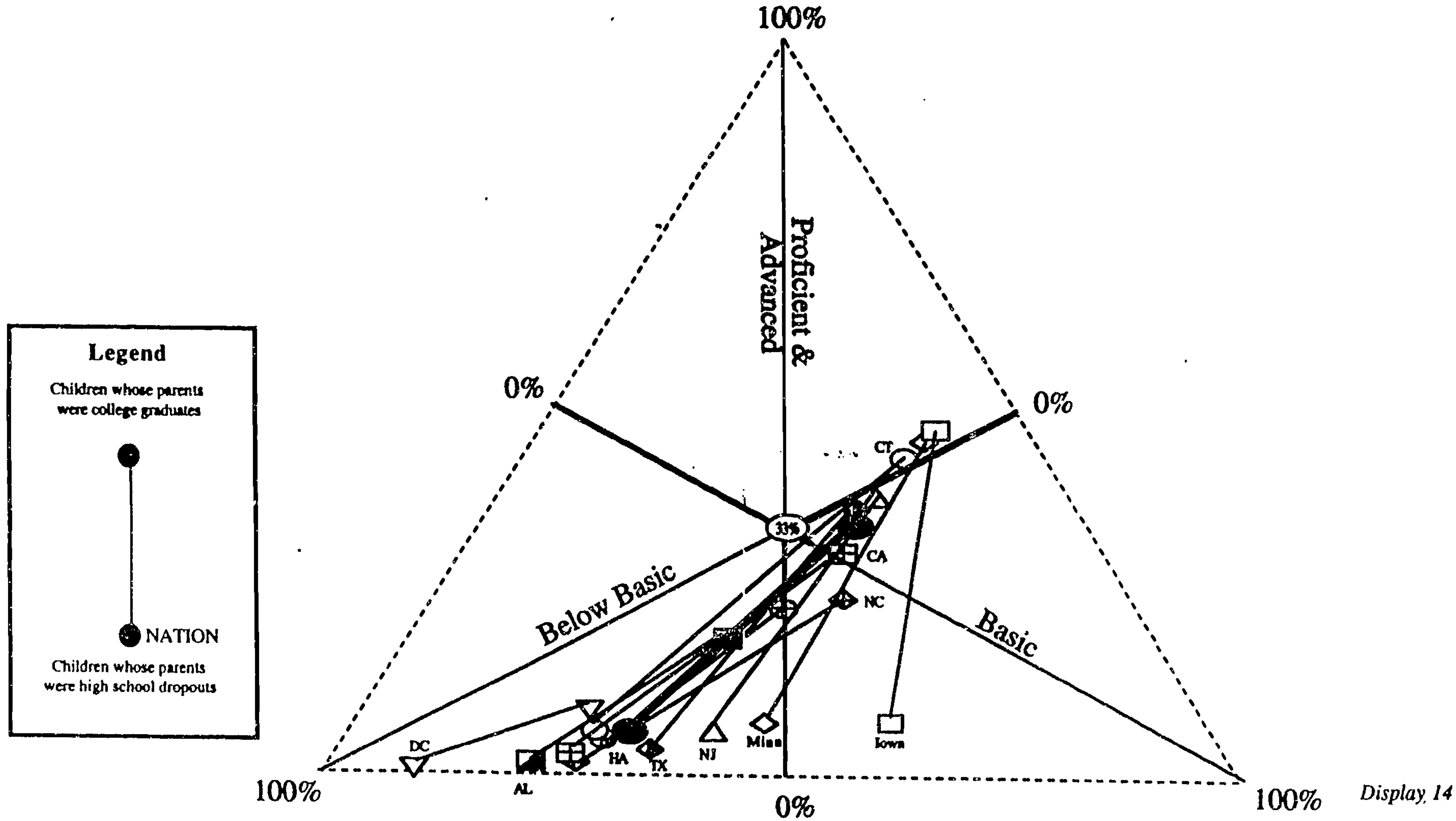
33

1992 8th Grade NAEP State Mathematics Assessment for Children Whose Parents Graduated from College



Display 13

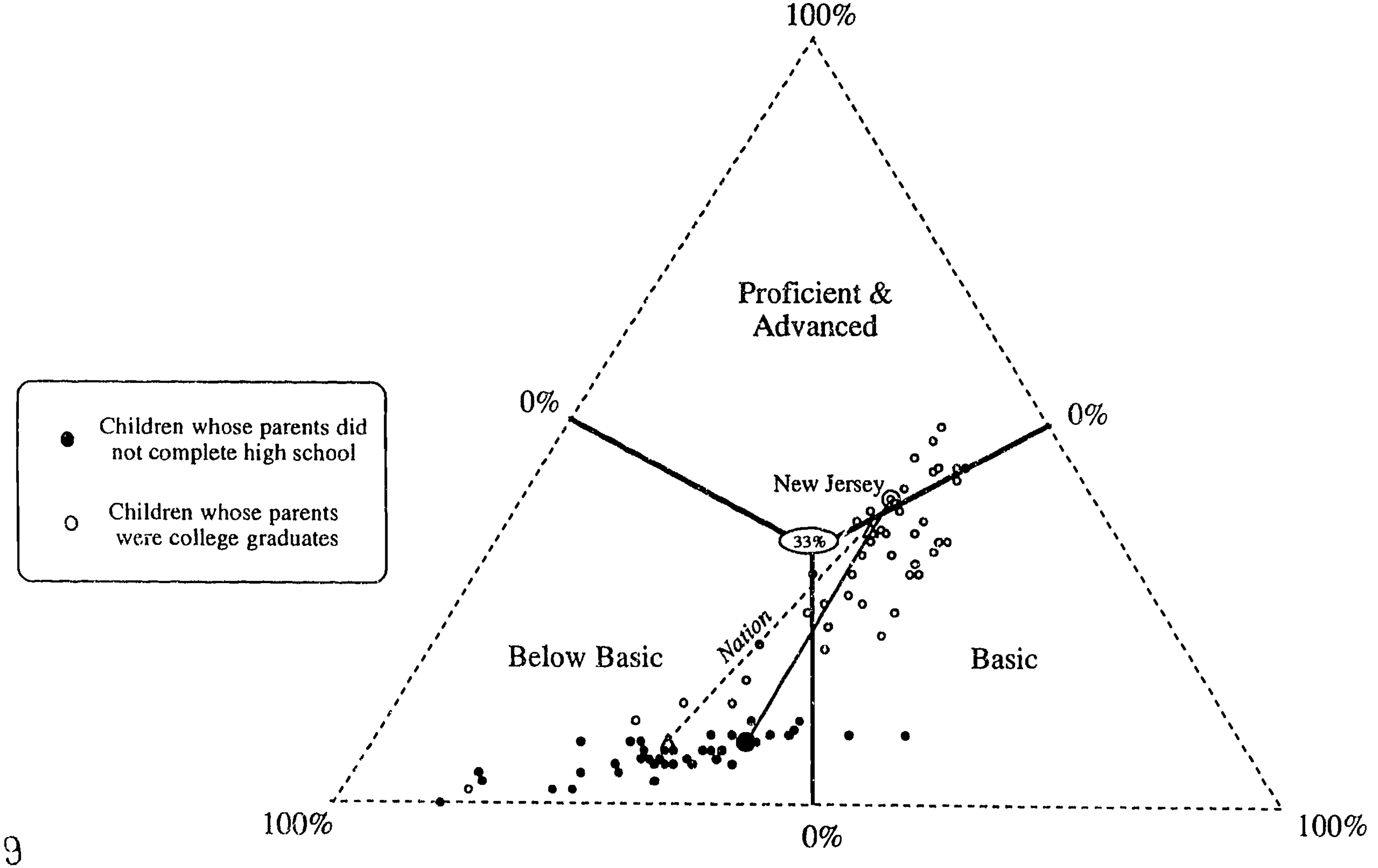
1992 8th Grade NAEP State Mathematics Assessment



Display 14

37

1992 8th Grade NAEP State Mathematics Assessment



Display 15