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ABSTRACT

It is important to develop instructional sequences that build on students' current understandings and support shifts in their current ways of thinking. As part of the pilot work for a project on mathematics teaching, classroom performance assessments were conducted to obtain baseline data on students' current statistical understandings. The assessments were conducted in three sessions of a seventh-grade class. The assessment task was designed to provide information about students' current understandings of the mean and graphical representations of data because these ideas were the focus of a statistics chapter students previously studied. Students worked in small groups on the three performance tasks, each of which is described in detail. The analysis shows that students typically viewed the mean as a procedure that was to be used to summarize a group of numbers regardless of the task situation. Data analysis for these students meant "doing something with the numbers," an idea grounded in their previous mathematics experiences. Students' conversations about graphical representations highlight the procedures for constructing graphs with no attention to what the graphs signify and how that relates to the task situation. To help students develop a sense of data analysis as more than just "doing something with numbers," it is necessary to create tasks that are relevant to middle school students. An appendix contains a list of 69 sources for additional information. (Contains 8 figures and 11 references.) (SLD)

An Analysis of Students' Statistical Understandings

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An Analysis of Students' Statistical Understandings

In our past work we have developed an approach to instructional design that is generally consistent with the theory of Realistic Mathematics Education (RME) developed at the Freudenthal Institute in the Netherlands. It can be characterized as a "bottom up" approach in that the designer's goal is to support students' progressive mathematization of their initially informal, pragmatic problem-solving activities in experientially-real situations (Gravemeijer, 1994). The first phase of an instructional sequence involves students in an exploration of several problem situations set within a context that is real to them. During this initial phase it is important that students develop a genuine need to construct informal mathematical arguments. In the second phase, instructional activities are developed to support students' development of *models of* their initially informal mathematical activity. These models might involve the use of physical materials and computer-based tools and can result in the development of pictures, diagrams, charts, and non-standard and conventional notations. In the third phase of a sequence, students begin to generalize their informal models. The instructional activities at this phase are designed to make it possible for these *models of* informal activity to take on a life of their own and become *models for* increasingly abstract mathematical reasoning that remains rooted in situation-specific imagery. In the final phase of a sequence, the generalized models are considered from a more mathematical point of view. This approach to design involves conjecturing both possible learning trajectories for students and means of supporting students' development along these provisional trajectories. The primary elaboration we have made to the RME approach in our work involves locating students' conjectured mathematical activity in social context, thereby explicating the assumptions that the designer necessarily makes about the classroom microculture within which students act and interact.

In our current work, we are refining our approach to instructional design in the context of students' development of statistical thinking in seventh and eighth grade. As part of the pilot work for this project, we read the literature on statistics teaching and learning (see Appendix) in order for us to clarify what the "big ideas" should be in statistics at the middle-school level. There are actually only a handful of studies available that focus on students' statistical understandings. These studies fall into two categories: (1) studies that examine students' understanding of the mean and

(2) studies that examine students' statistical understandings in the context of data analysis. All of the early research focuses on students' misunderstandings and misconceptions of the mean (e.g. Mevarech, 1983; Pollatsek, Lima & Well, 1981, Strauss & Bichler, 1988). More recently, researchers have studied how students use the mean to summarize and compare data sets (e.g., Gal, I., Rothschild, K., & Wagner, D.A., 1990; Mokros and Russell, 1995) These studies emphasize that traditional instruction may provide students with the appropriate algorithm for the mean, but leave them with an incomplete conceptual understanding. An emerging research trend is focusing on studies where students are involved in the more complex activity of data analysis (e.g., de Lange, van Reeuwijk, Burrill, & Romberg, 1993; Hancock, Kaput, & Goldsmith, 1992; Jacobs & Lajoie, 1994; Konold, Pollatsek, Well, & Gagnon, in press; Lehrer & Romberg, 1996). Typically, these studies outline the process by which students analyzed and reasoned about data in more innovative instructional approaches. Clearly, the two categories of studies highlight different aspects of statistics instruction. The first set of studies emphasize the mathematical *content* (the mean) and the second set of studies document the mathematical *process* involved in data analysis. We believe it is crucial to transcend this dichotomy between content and process by developing an instructional approach that focuses simultaneously on data analysis and on mathematical content.

In the context of data analysis, the mathematical content in statistics must move beyond simply understanding the mean to more unifying big ideas. For example, several authors stress the importance of students coming to view data as an entity as opposed to a collection of individual data points (Hancock et al., 1992; Konold et al., in press; Mokros & Russell, 1995). One idea that helps identify what might be involved in viewing data as entity is that of a space of potential data values. In particular, we conjecture that students who view data as entity see the individual data points as located within a space of possible values. As an example, Hancock et al. document that the students in their study rarely used the axis plot option of TableTop even though they had used the software to conduct data analyses for a year and could explain the meaning of the icons when shown on axis plots. They suggest that the very thing that made the axis plot powerful – the fact that it corresponded to a space of possible values, rather than to a single value – also made it harder to understand. In other words, since the students did not conceptualize the individual data points as located in the space of all possible values, the possibility of using an axis plot did not occur to them.

A similar analysis holds in the case of Konold et al.'s observation that the students in their study rarely used the histogram option of the DataScope software. A histogram involves structuring the space of all possible data values into equal intervals. These examples illustrate the importance of a space of potential values as a big idea in statistics instruction.

A second big idea, closely related to the first, that came to the fore in our reading of the literature is that of group propensity (Konold et al., in press). In defining group propensity, Konold et al. refer to the rate of occurrence of some data value within a group that varies across a range of data values. For example, the data value in question might be that of being a boy rather than a girl. Unless individual data points are located within a space of possible data values in which they can take on the values of boy or girl, the propensity of being a boy cannot be formalized as, say, 65%. As Konold et al. observe, the possibility of comparing groups in terms of means or relative frequencies did not occur to the majority of students in their study when they conducted data analysis. This can be accounted for in terms of their lack of understanding of the big ideas of a space of potential values and of group propensity. The development of these two big ideas together constitute major steps towards understanding the statistical concept of distribution and are, therefore, mathematically significant. We have also pointed out the crucial role these two big ideas play in data analysis. For us, these two big ideas bridge the dualism between content and process.

In order to support students' development of an understanding of data analysis along with an understanding of the big ideas in statistics, it is important to develop instructional sequences which (1) build on students' current understandings and (2) support shifts in their current ways of reasoning. As part of our pilot work for our current project, we conducted classroom performance assessments in order to obtain baseline data on students' current statistical understandings. The assessments were conducted during the fall semester of 1996 in three sessions of a seventh-grade class. During the sessions, a former middle-school teacher who was a member of the research team posed tasks to the students as they worked together in groups. The tasks were designed to provide information about students' current understandings of (1) the mean and (2) graphical representations of data (inscriptions)because these two topics were the focus of the statistics chapter in the textbook series used by the students in their previous instruction. By focusing on students' current ways of reasoning, the subsequent instructional materials could build from their current knowledge. The purpose of this paper, then, is to document the analysis of these performance tasks. This analysis will then serve to inform subsequent decisions concerning instructional development.

Results of Analysis

The general format for the three mathematics class sessions in which the performance tasks were conducted was a whole-class introduction to the task, student collaboration in small groups, followed by a whole-class discussion of their solutions. Students worked in groups composed of from 3 to 6 students and the number of groups sometimes varied from task to task. In the following sections of this paper, we will begin by describing the context of the task, the design decisions underlying the task, and our anticipations of how students would respond to the task. Second, the small-group work is analyzed in order to highlight the various solution methods. Finally, the whole-class discussions are analyzed to clarify students' understandings.

Task 1: Spare Time

In the first task shown in Figure 1, students were given a list of 24 activities collected from a survey in which their classmates were asked what they liked to do in their spare time. Students were asked to organize the list so that the principal could more easily present the results on a bulletin board for Parent's Night.

You have collected the following information from your classmates concerning what they like to do in their spare time. Organize the information so that the principal can more easily present the results on a bulletin board for Parent's Night.

read	*watch MTV*	*watch re-runs of the X Files*
exercise	*listen to music*	*play volleyball*
ride my bike	*read comic books*	*watch old movies*
write letters	*watch TV*	*clean up my room*
practice my guitar	*talk on the phone*	*jog*
trade baseball cards	*shoot basketball*	*play with the dog*
play the piano	*go to the movies*	*work on my stamp collection*
watch sports on TV	*hang out at the mall*	*listen to the Grateful Dead*

Figure 1. Task Posed About How Students Spend Their Spare Time.

This task was designed with categorical data so students could not use the mean. With the mean eliminated, we wanted to see if students would then consider using inscriptions with this data set or if they would organize the data in some other way. We anticipated that students would not use inscriptions, but would form categories. We also thought that some topics might be problematic for students because we could imagine them being placed in more than one category. For example, *watch MTV* could be placed in a category entitled *Watch TV* or *Listen to Music*. As it turned out, this issue was not a problem for most of the students.

All the groups of students began this task by organizing the data under various headings. We would say, then, that the interpretation of this task as one of creating headings to organize the data was taken-as-shared. As a result, the whole-class discussion focused on students' different ways to form the headings.

Group Work

In analyzing the small group work, we have identified three different solution approaches developed by the eight groups of students: (a) creating categories, (b) creating clusters and (c) noting relative frequencies. Students who offered solutions that we call *categories* made two or three broad headings and then listed each topic from the task under one of these category headings. In our view, to form a category means making a distinction such that every item falls on one side or the other of that distinction. In other words, categories are mutually exclusive and partition the data. Three of eight groups of students formed categories.

The groups who approached the task by forming categories began by examining the data and forming initial categories which essentially were conjectures of how they anticipated the data could be partitioned. By creating these initial categories the students explicitly formed a set of criteria for the category which allowed them to justify their placement of topics into each category. As they then began to place each topic within a category, they sometimes had to adjust the initial categories in order to place more data items within them. For example, one group began with initial categories of *Physical Activities, Reading and Writing,* and *TV*. As they worked through the list of topics, they identified three data items (*play piano, play with the dog,* and *trade baseball cards*) that did not unambiguously fit into any of their initial categories. To resolve this difficulty, they changed the second category to include hobbies which then allowed them to add these three data items. Making this adjustment to the second category explicitly changed the set of criteria for the category. This then allowed the group of students to justify the addition of the new data items.

Students who made what we called *clusters*, created between 6 and 8 broader headings which essentially were a more succinct list of topics describing what the students did in their spare time. For us, forming a cluster means simply finding broad headings that define a somewhat smaller subset of the data set. This is different from creating a category in that forming a cluster does not involve making a distinction such that each item falls on one side or the other of that distinction. In other words, clusters are *not* mutually exclusive. Four of eight groups of students formed clusters.

The groups who formed clusters began by inspecting the topics and identifying several that were related in some way. They would then cross these topics off the list and create one cluster heading that encompassed this group of similar topics. The students continued to make clusters (between 6 and 8) until all topics were crossed off the list. This approach further differs from forming categories in that these students did not form initial conjectures about how to partition the data. Instead, they partitioned the data set in action as they examined the individual topics. Consequently, they did not formulate explicit criteria that could serve to justify their placement of topics into one cluster rather than another. For example, one group that formed clusters completed the task and then noticed that the topic of *practice the guitar* was not crossed off their list. In the subsequent discussion, the clusters of *Hobbies, Physical activity*, and *Music* were all suggested as possible placements for the topic of *practice the guitar*. In forming their clusters, this group of students had not explicitly created a set of criteria that would allow them to justify the placement of topics within the cluster. Therefore, the specific placement of the topics was not an issue. It was only important that a cluster exist that could accommodate the topic. Depending on the individual student's interpretations, *practice the guitar* could be placed within at least three different clusters.

The final solution approach we call *relative frequencies*. The one group of students who formed relative frequencies created categories, but instead of listing the topics from the task under each category, they recorded the fraction of the topics that fell into each category. In other words, they mathematized the partitionings they had created. Although only one of eight groups solved the problem in this way, we feel the difference in approach is highly significant as this group of students looked at the problem quantitatively. For example, beside the category heading *Watching TV*, they wrote 4/24, indicating that 4 of the 24 topics fell into this category. This indicates that these students interpreted the categories they formed as, at least, additive frequencies.

It is important here to clarify the distinction between additive and multiplicative frequencies. To interpret 4/24 additively means that these students partitioned the whole (24) and one of those partitions contained four items. These four items are viewed as a subset of the whole and the relationship between the part and the whole is fixed. To interpret 4/24 multiplicatively, they would have to think about the relationship between the part and the whole as some sort of change or variation is introduced into the task. For instance, if more topics were added to the problem, we could ask the students to predict how many of the new topics would fall into a certain category. Another possibility would be if we asked the students to compare a category containing 4/24 topics with a category from another survey containing 7/45 topics. In these instances the students would have to think about the relationship between the part and the whole as they vary in the first example and to compare data sets with an unequal number of items in the second example. The relationship between the part and the whole is no longer static and more than part-whole reasoning would be required — proportional reasoning would be necessary. Reasoning in this way is central to what Konold, Pollatsek, Well, and Gagnon (in press) refer to as a statistical perspective — attending to features of the data as an entity (the aggregate) as opposed to features of individual data points. The limited nature of this task does not allow us to differentiate between additive and proportional reasoning, which is why we can only claim that the students in this group established additive relative frequencies.

Whole-class Discussion

As the groups that formed clusters shared their solutions in whole-class discussion, they questioned one another about the usefulness of their clusters framed against their desire to reduce the number of clusters. The first group that explained their reasoning had formed 11 clusters and other students argued that two or more of those clusters could be combined under a broader cluster. For example, the group that formed 11 clusters had *Listen to Music* and *Playing Musical Instruments* as two different clusters. A student suggested that these two clusters could be combined into one cluster entitled *Music*. The discussion continued with several other suggestions of combining clusters. As groups that formed categories shared their solutions, this same type of discussion did not occur since they only had two or three categories.

In the on-going discussion, the students did not question the placement of individual topics within particular clusters even when prompted by the teacher. For example, the teacher explicitly raised this issue by asking the first group that shared their solution where they placed *watch MTV*. From our perspective, *watch MTV* could have been placed under their cluster of *Watch TV* or *Listen to Music*. The group stated that they had placed it under *Watch TV* and there was no further discussion. It therefore appears that, from the students' perspective, there was no need to justify how they had organized the data — they did not feel it was necessary to develop publicly accepted criteria for their decisions. The focus of the whole-class discussion was on the *procedure* of forming categories and clusters rather than the *reasoning* underlying the placement of topics within particular categories and clusters.

Although we mentioned three different solution approaches to this task, the teacher, in action, judged that there were only two. Only in retrospect did we recognize the significance of the relative frequency approach. Because of this, only the two approaches that we call categories and clusters were addressed in the whole-class discussion. As a result, the teacher summarized the two types of solutions that were highlighted and then attempted to focus the discussion on the differences between these two approaches. She pointed out that some groups had a list for the Principal of between 6 and 8 headings (clusters) without the topics included. The other groups, she noted, had a list of only 2 or 3 headings (categories) but they had included each topic underneath. Similar to the previous discussion on the placement of individual topics, the students did not appear to see any significance in the difference between the approaches and there was no further discussion. Since the students had rarely made any reference to either the task setting or how their data organizations would be used, it could be argued that they perceived the task as merely a procedure which lacked any mathematical rationale. They simply interpreted this as a task they were to complete by grouping topics. If this was the case, then these students would have no means of evaluating the two approaches other than their personal preferences and there would be no need to discuss the issue.

Task 2: How Much TV?

In the second task which is shown in Figure 2, students were given results from a survey of 30 students in which they were asked how much television they watch in one week. The students were asked to summarize and present the data in some form so that when posted on the bulletin board parents would be able to quickly understand the results.

Below are the results of a survey taken of 30 seventh graders to find out how many hours of television they watch in a week. The Principal has asked you to summarize and present this data in some form so that parents will be able to understand it quickly when it is posted on the bulletin board. The Principal also asks you to write a short report for parents explaining what the data shows.

1.5	*21*	*12.5*	*0*	*2.5*	*15*	*23*	*19*	*4*	*14*
8	*16*	*13.5*	*16.5*	*6*	*4.5*	*9*	*18*	*5*	*10.5*
8.5	*6*	*3*	*9*	*11.5*	*3.5*	*19.5*	*13*	*10*	*9*

Figure 2. Task Posed About How Much TV Students Watch.

In designing this task, we were interested to see if students would summarize the data set by using an inscription or the mean. The data set was purposely designed with a large range (0 - 23) which, for us, would make the mean an inappropriate summary for this task situation. We anticipated that students would use both approaches to summarizing the data despite the large range. All the groups but one offered a solution that included an inscription.

Group Work

Ultimately, only one of the groups solved this task by finding the mean of the data set. For this group, the task appeared to be to summarize a large set of numbers. These students' prior experiences in school mathematics could have influenced their interpretation of the task. Typically, in traditional school mathematics, a large set of numbers is summarized by calculating the mean. The remaining groups made some sort of graph to describe how much television was watched although some of these groups discussed the appropriateness of using the mean.

One group in particular had a very intense discussion about whether or not the mean was an appropriate way to represent the data set. One student in the group, Trent, wanted to use the mean because the task for him was to tell about the 30 students "altogether" and that, he argued, is precisely what the mean did. Others in the group argued that since some students only watched 1.5 hours of TV, then the average of 10.56 is "way off" and "It's so off, you cannot use the answer." The group's discussion seemed to focus on whether or not you could actually use the mean and not on whether or not the mean was an appropriate representation of this data set. After several minutes of discussion, it was not clear to us whether the students felt that the mean was inappropriate because of the high variability in the data set or if they felt that since some of the data points were so far from the mean that it did not work for this data set. Clearly, Trent and the members of his group had different notions of the mean. Since the group could not come to an agreement, Trent decided to use the mean and the others in the group decided to make a graph which is shown in Figure 3.

In making their graph, the rest of Trent's group decided to organize the data into categories from 0 to 10, 10 to 20, and 20 to 30. One student in the group then pointed out that the "highest on here is 23." As a result, the group changed the upper bound in the last category to 25. We find this interesting since the highest data point is 23.5 and changing the upper bound of the last category from 30 to 25 did not change the height of the bar. It did, however, result in unequal intervals. As the group began to draw their graph, they changed the category labels to 0 to 10, 11 to 20, and 21 to 25. Even though the graph is reminiscent of a histogram, we believe that for this group it was a bar graph over intervals. Changing the upper bound from 30 to 25 indicates that this group of students did not view this data as positioned within a space of potential data values. The way the group created the categories as described above indicates that they were partitioning the data items rather than creating intervals that fell along a continuum of potential data values. The spaces between the bars also indicates that each category was a separate subset of the data rather than intervals in the space of possible data values.

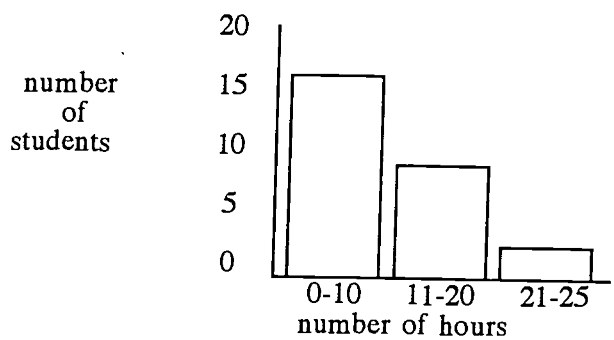

Figure 3. Group One's Graph for *How Much TV?*

The second group's graph is shown in Figure 4. These students began by grouping the data into categories from 0 to 5, 6 to 10, 11 to 15, 16 to 20, and 21 to 25. However, when they drew their graph they did not make bars but simply put a line at the upper limit of each category. Similarly, they did not list the categories (0 to 5, 6 to 10) when they labeled the axis on their final drawing, but instead wrote only the upper limit of the category. In addition, they used a large dot to mark the endpoint of the line. It is possible that this group viewed the data as distributed along a continuum, but we cannot verify this with the available information. If this were the case, we would classify their graph as a histogram even though it does not conform to the conventions for drawing histograms. The most we can claim with the available information, is that this group categorized data items.

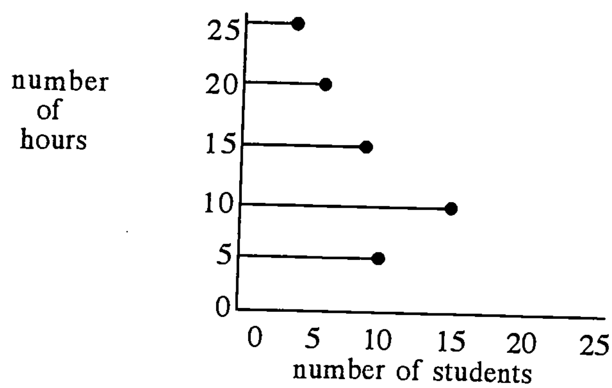

Figure 4. Group Two's Graph for *How Much TV?*

The third group's graph is shown in Figure 5. This group began by ordering the data from the least number of hours of television watched to the greatest. They then decided to group the ranked data into categories. They chose to make five categories with six data points in each category. On the bar they wrote the range of the data points signified by each bar. This group created a bar graph in which each category, indicated by a bar, signified six data items. The numbers written on the bars to record the values of the data items have gaps between them, indicating that this group of students also did not view this data as distributed on a continuum within a space of possible values.

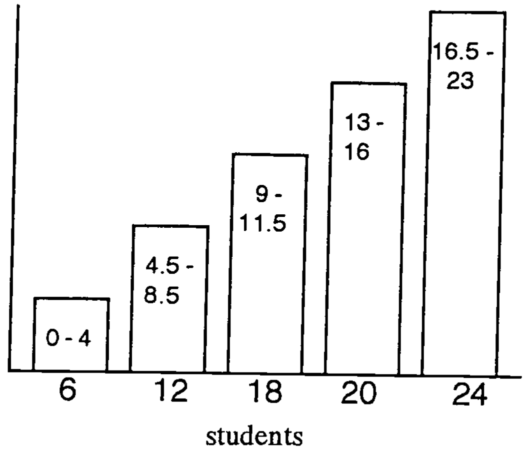

Figure 5. Group Three's Graph for *How Much TV?*

The fourth group's graph is shown in Figure 6. This group began by rounding all the numbers to the nearest whole number and then ordering the data items. Their graph contained 12 bars that indicated the hours of TV watched. This group of students seemed to view the data as individual items that could be ordered. We will say more about this group in the next section.

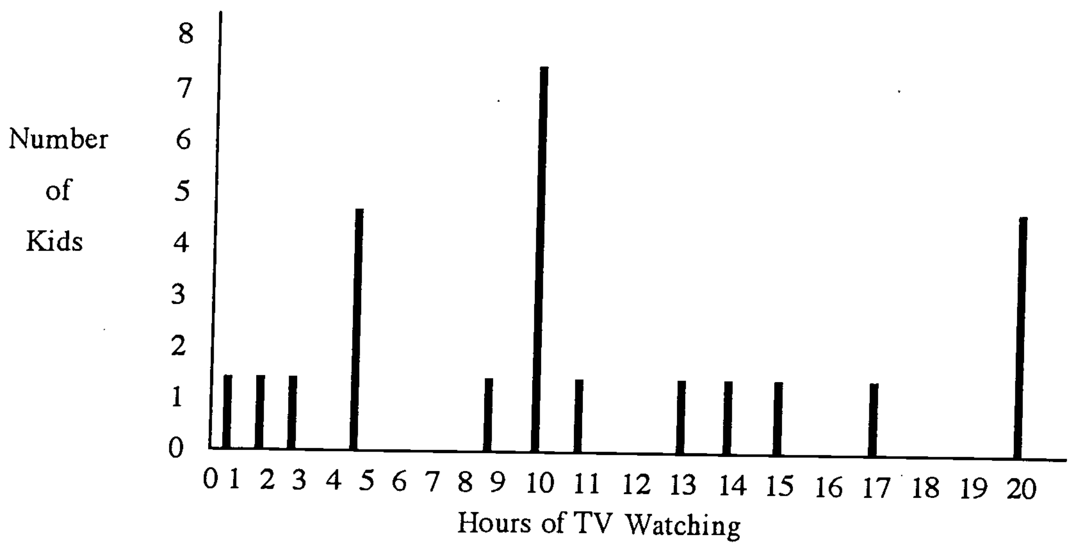

Figure 6. Group Four's Graph for *How Much TV?*

Basically two approaches were used by the groups of students when creating their graphs. The first approach involved ordering individual data points. The students in Group Four exemplified this approach when they created their graph (see Figure 6). Creating categories for ordered data points is the second approach. Groups One, Two, and Three expressed this approach in their graphs (see Figures 3, 4, 5). In both of these approaches, the data set was viewed as a plurality of individual data points that could be rank ordered and/or categorized. It appears that none of the groups viewed the data set as a global whole that could be distributed along a continuum. Had they done so, it is reasonable to assume they would have drawn a histogram. In contrast to a bar graph over intervals, a histogram involves structuring the space of all possible data values into equal intervals. It is important to point out that simply drawing a histogram would not necessarily mean that students viewed the data set as an entity that could be distributed within a space of possible data values. We would also have to take into consideration how the students reasoned about the data and the resulting graph.

Whole-class Discussion

During the whole-class discussion, the four graphs previously described were presented on the board and then became topics of discussion. After the first group described their graph (see Figure 3), the teacher asked the rest of the class if they had questions or comments about this graph. There was no discussion. Next, the second group described their graph (see Figure 4) and the teacher then initiated a discussion by asking students to clarify the similarities and differences between the two graphs.

Student 1: That's (points to Group Two's graph) a line graph and that's (points to Group One's graph) a bar graph.

Teacher: That's a line graph and this is a bar graph. Anything else?

Student 2: I thought it was supposed to be bars and not little lines... like bars.

Teacher: Why do you think it is bars?

Student 2: Because if you do a line it is supposed to go up at the time when it goes up and it goes down when... it goes up when the rate is high and goes low...

Student 3: I think it is supposed to have bars when it goes vertical [sic] like that.

Teacher: What if she is calling these skinny bars? What if she is saying these are really just skinny bars?

Student 4: With dots on the ends of them?

Student 5: With dots on them? I mean, you could do that but you wouldn't have a line on them, you would just have the dots.

Student 6: A line graph is supposed to be connected to other line segments.

It is significant that the focus of the discussion was on the form of the graphs and not on what they signified. These students were simply concentrating on what they remembered about the conventions for drawing graphs. This same type of superficial discussion occurred after the third group presented their graph (see Figure 5). Students were again asked to clarify similarities and differences of the graphs. In this discussion, the students' contributions focused only on the direction of the bars. If we consider students' prior school math experiences, this does not seem too unusual. In traditional mathematics instruction, a discussion about graphs would highlight the conventions for drawing graphs. This could explain the students' emphasis on surface features like lines, bars, dots, positioning of bars, and connecting dots rather than on what those lines, bars, or dots signified and how that related to the task situation. These discussions were similar to the whole-class discussion for the Spare Time task where the students were interested in the *procedures* of forming clusters and categories rather than the *reasoning* underlying the placement of topics.

As the fourth group was presenting their graph (see Figure 6) they decided to modify it by rounding all the data items to either 10 or 20, resulting in only two bars signifying the hours of TV watched. They did not finish drawing their new graph but described it for the other students. In their initial graph (shown in Figure 4) they ordered but did not categorize the individual data items. In their second graph, which they described as containing only two bars (one at 10 and one at 20), they categorized the ordered data items. It may be that as this group listened to the other three groups discuss how they made their graphs, they noticed that all three groups had categorized their data. It is possible that categorizing the data was becoming taken-as-shared in this classroom which prompted this fourth group to change their graph to fit with this emerging interpretation.

Tasks 3 & 4: Basketball All-Star & Trip Decision

In the Basketball All-Star and Trip Decision tasks, students were asked to make a decision based on given sets of data. We discuss these tasks together since they were formatted in a similar manner. We designed these tasks in an attempt to gain information on how the students would deal with the issue of variability as it related to the mean. We anticipated that some groups would reason that the data set with the larger mean was the better choice without going back to the task situation and considering the impact of variability on the decision in these particular instances. We therefore designed the tasks so that the data set with the larger mean also had the greater variability. For us, then, the data set with the larger mean would not be the better choice because in these two situations (scoring in basketball and temperature ranges) consistency would be more important when making a decision.

Basketball All-Star

In the Basketball All-Star task shown in Figure 7, students were given a listing of the number of points scored by each of two basketball players in each of eight games. They were then asked to decide which player should be selected to play in the all-star tournament based on these scores.

One player will be selected from the Meigs basketball team to play in the all-star tournament. Below is a listing of the points scored by the top two candidates for the last eight games of the season. Based on this information, present an argument to support the selection of one of the players.

Player A: 11	*31*	*16*	*28*	*27*	*14*	*26*	*15*
Player B: 21	*17*	*22*	*19*	*18*	*21*	*22*	*20*

Figure 7. Task Posed About The Basketball All-Star Tournament.

Group work. This task was approached in two distinct ways. The majority of students, five of eight groups, solved this task by calculating the total or the mean. The remaining three groups also initially found the mean or the total, but then they reconsidered the task situation and decided the player with the higher mean was not the better player for the tournament. For the five groups who calculated the total or the mean, this task was about totaling or averaging the points of each player and determining the winner by comparing the outcome. Each of these groups selected Player A because he had the higher total and/or the higher average number of points. For these groups, the mean provided the best summary of the data irregardless of the situation. If we consider the prior school experiences of these students, reasoning about the problem in this way seems reasonable. In traditional school mathematics a group of numbers is often summarized by calculating the mean.

The other three groups of students initially began the task in the same way as the groups described above. However, they subsequently selected Player B even though his total points were lower than Player A. After calculating the total or the mean, these groups went back to the task situation and decided that the player with the higher mean was not necessarily the player that should be sent to the tournament. These discussions will be elaborated in the next section.

Whole-class discussion. The teacher began the whole-class discussion by asking students to defend their choice of Player A or Player B as the one to send to the all-star tournament. The first group to share their thinking argued for sending Player B.

Student: Our group said that you should send Player B to the tournament because he has a...even though Player A's average [sic] is higher than his, which was only by eight points, he has a more steady...in his games...his points...they're more...they're not so up and down like Player A's are...where one day... he goes from 11 points to 31 points so that's why we said Player B.

Only one other group shared their thinking and they argued for sending Player A to the tournament. However, their argument went beyond their reasoning about the mean. This group had been challenged by another group that was sitting at the same table and as a result, expanded their argument. They created a situation to explain the variability in Player A's scores and argued that Player A, in addition to having the higher average, was probably a "team player." His low scores (11, 16, 14, 15) indicated that he was giving the ball to other players and he probably earned high assists in those games rather than high points. His high scores (31, 28, 27, 26) indicated that he helped the team out when they were falling behind. This group continued their support of Player A by creating a situation to downplay Player B's consistent scoring. They argued that Player B had scores that were about the same which indicated that he had a "personal goal" to achieve in each game and was not thinking of the team. This group believed the mean was the best summary of the data sets and the counterargument about consistency in scoring did not alter their position. In order to defend their choice of selecting the player with the higher mean, this group appeared to rely on their knowledge of basketball to create a narrative that would support their choice of Player A.

Trip Decision

In the Trip Decision task shown in Figure 8, students were given data on the temperatures in Boston for the third week of September and April for the past three years. The students were asked to use this data to decide if next year's school trip to Boston should be taken in September or April.

The students are planning to go to Boston during the school year in 1997-98. The Principal has agreed that they may miss a week of school either the third week in September or the third week in April. You have been asked to research the weather during these times and make a recommendation about when to go to Boston.

Below are the temperatures for each of these weeks for the past three years. Based on the information given, prepare a report for your Principal which clearly explains the reasons for your choice.

September:

1996	77	71	80	75	73	79	77	average for week: 76
1995	75	71	77	80	76	70	69	average for week: 74
1994	79	71	74	79	77	73	72	average for week: 75

April:

1996	84	80	76	76	68	62	58	average for week: 72
1995	79	83	87	90	89	86	81	average for week: 85
1994	56	57	68	73	79	80	84	average for week: 71

Figure 8. Task Posed About The School Trip.

Group work. This task was approached in two distinct ways. Two of seven groups of students solved this task by calculating the mean. The remaining groups did not perform any calculations in determining their solution. The two groups that calculated the mean found the average of the three weekly averages given in the task for September and April which were 75 and 76 respectively. They selected April because it had the higher average and for them, the average was the best summary of the two data sets.

The remaining five groups did not perform any calculations as they reasoned about this task. Instead they focused on the daily temperatures presented in the task and formed arguments based on the consistency of the temperatures. For example, these groups suggested that September would be the better month for the class trip because the weather was more predictable. Their arguments will be discussed in more detail in the next section.

Whole-class discussion. The teacher began the whole-class discussion by asking groups to offer arguments for taking the trip in either September or April.

Student 1: Our group chose to go in September because it's not...there's not like really big drastic temperature changes; where as in April it goes from...I know in '94 it went from like 56 all the way to 80 degrees in one week. So that's why we chose September, it has pretty much the same temperature.

Teacher: OK, it's kind of stable (writes on board). Alright, someone else?

Student 2: We say September because the weather is steady...like and the average weather in April for these three...like it went from in '96 it was 72, '95 - 85, '94 - 71. So you can really predict what kind of weather it's gonna be [in September] it was 75, 74, 76 so you know it's going to be around 70-something and... it's just too cold [in April]...56 and 57 degrees...you want a warm weather...you don't want to be wearing no coat and stuff.

Teacher: You don't want to have to pack all that stuff do you? OK...What about the fact that this one (points to April on the board) has a higher average. Did you calculate the overall average? It has a higher overall average, so shouldn't it be warmer then?

Even though two groups did approach this task by calculating an average this way of reasoning about the task did not emerge from students' arguments. Although the teacher brought this issue up in the whole-class discussion, the subsequent interchange was minimal. In the ensuing discussion, one student suggested that a one degree difference was not that significant and another student suggested that the unusual 85 degree average "kicked the average up" for April. This lack of interest in the mean is interesting when contrasted to the Basketball All-Star task where the majority of groups calculated the mean and the mean was explicitly included in the arguments during the whole-class discussion. This could be accounted for by the fact that this task seemed to encourage qualitative judgments rather than calculations. For example, in the Basketball All-Star task, some students found the total number of points to make a decision. In this task, adding the temperatures to find a total did not make sense to students. In their out-of-school practices, students do not add daily temperatures to make a decision. Instead, students made qualitative judgments based on the inspection of individual data points. Another possible explanation for the lack of interest in the mean could be related to the fact that this was the last task presented to these students. In the earlier tasks we saw the impact of prior school mathematics on students' reasoning. For example, we pointed out that students seemed to view the first task as a typical school mathematics task involving a *procedure* of categorizing data points. Similarly, the second task appeared to be interpreted as a task about the *procedure* of making a graph. In the third task, the majority of students reasoned that the mean was the best summary of the data set irregardless of the situation. It is possible that after interacting with the teacher and their peers for three days on these non-school-like tasks, that students began to reinterpret the social situation of the mathematics classroom and began to construct new beliefs about what was expected of them in this situation.

Conclusion: Implications for Instructional Design

As stated prior, our purpose in this paper was to document the analysis of classroom performance assessments that we conducted as part of the pilot work for our current research project. We were interested in gathering information about students' current statistical understandings in order to develop instructional materials. The tasks were designed to provide us with information about students' current understandings of (1) mean and (2) graphical representations.

In our analysis we found that students typically viewed the mean as a procedure that was to be used to summarize a group of numbers regardless of the task situation. Data analysis for these students meant "doing something with the numbers" which was grounded in their prior school mathematics experiences. Similarly, we found that students' conversations about graphical representations highlighted the procedures for constructing graphs with no attention to what the graph signified and how that related to the task situation. These findings will have important implications for us as we design instructional sequences for our current research project.

It will be crucial for us to help students develop a sense of data analysis as being more than "doing something with the numbers." We can begin to do this by creating task situations that are relevant to middle school students. Of course, tasks that are interesting to students are not enough. We found in our analysis that interesting, non-school task situations were also proceduralized by the students. We will need to spend time building a strong context in order to pull students away from their procedural orientation. In establishing this context, it will be important to immerse students in the situation by discussing the problem or issue being investigated. These discussions can help students clarify the significance of the problem, identify aspects of the problem that could be measured, and consider ways those measurements could be made. After this extensive orientation to the task, we hope that students will be more grounded in the situation and we can then support a shift in their reasoning towards data analysis as inquiry rather than procedure.

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