10. Assessing Students' Statistical Problem-solving Behaviors in a Small-group Setting

Frances R. Curcio
Alice F. Artzt

Purpose

The ability to interpret and predict from data presented in graphical form is a higher-order skill that is a necessity in our highly technological society. Recent recommendations from the mathematics and science education communities have therefore stressed the importance of engaging learners in real-life statistical tasks given in a setting that will promote effective problem solving. Since the small-group setting has been shown to be a fertile environment in which problem solving can occur, we have used that setting for engaging students in data analysis tasks. However, there is a dearth of ideas related to how to assess students' behavior, thinking, and performance in such a setting. The purpose of this chapter is to describe a framework for assessing students' problem-solving behaviors on a graph task as they work within a small-group setting.

INTRODUCTION

Statistical problems that require data analysis are not encountered only when one studies statistics, but rather, permeate other disciplines as well. For example, mathematics, the physical sciences, the biological sciences, and the social sciences all employ data analysis as a tool for solving problems. Yet, although many current assessment items require that students calculate specific statistics (e.g., measures of central tendency, measures of dispersion) or locate specific information (e.g., reading a graph or table), opportunities to present statistics as a problem-solving process have been ignored (Garfield, 1993; Friel et al., this volume).

The small-group setting has been demonstrated as an effective environment for enhancing mathematical problem solving (e.g., Artzt & Armour-Thomas, 1992). Such a setting provides a safe environment in which students can brainstorm, share, and discuss their interpretations related to higher-level cognitive tasks. Small-group interactions can contribute to developing mathematical power in statistical reasoning (Curcio & Artzt, in review). Only recently have educators begun to identify assessment techniques in such a setting (e.g., Hibbard, 1992; Kroll et

al., 1992; Miller, 1992), recognizing the importance of assessing students' contributions to a group task (MSEB, 1993).

This chapter describes our efforts to design and apply a framework for assessing statistical problem-solving behaviors of students as they work in a small-group setting. This framework is demonstrated in the context of assessing the problem-solving of a group of middle school students working on a graphical task. It should be noted that the chapter deals with two separate but related facets of assessment that emerge in such a context: assessment of the *process* of problem-solving of a group of students, and assessment of the *quality* of the solution of a *graphical* problem. We also discuss integrative assessment techniques.

The chapter is organized in four parts. First, issues in assessment of performance on graphical tasks are noted, and the specific task given to our students is described. Next, a framework for assessing problem solving in a small group setting is described and adapted to the graphical task presented to the students. The use of this assessment framework is then demonstrated by applying it to the actual work of a group of four students, and the types of information about students' work processes that we were able to obtain are illustrated. Lastly, implications for instruction and assessment are discussed.

GRAPHICAL TASKS AND THEIR ASSESSMENT

Interpreting and analyzing data are problem-solving processes that are essential for dealing with information presented in many different forms, including but not limited to graphs and tables. Visual displays of data are found in reports and in the media, often being used to make decisions or to determine whether to support or reject arguments. Recognizing trends, extracting patterns, and extrapolating from data are higher-order problem-solving components of data interpretation and analysis.

There are several frameworks for analyzing graphic interpretations (Guthrie, Weber, & Kimmerly, 1993; McKnight, 1990; Pinker, 1990). This chapter uses a basic framework for analyzing students' responses that was presented in Curcio (1981, 1987). This framework involves notions of *reading the data* (i.e., extracting information explicitly and directly from the graph), *reading between the data* (i.e., combining and comparing data), and *reading beyond the data* (i.e., extrapolating and predicting from the data).

One of the most frequently used visual displays is the time series plot (Tufte, 1983). Found in science and social studies documents, the time series plot is a line graph of data recorded over a period of time. Using this type of display enables scientists and social scientists to examine patterns, recognize trends, extrapolate from the data, and make predictions. Recognizing the importance of such a visual display, a higher-order, open-ended, free-response task employing such a graph was designed to be the focus of a small-group assessment. The structure of the task is similar to extended constructed-response item-types found on a recent National Assessment of Educational Progress (NAEP; Dossey et al., 1993). The task was designed to be of interest to and mathematically worthwhile (MSEB, 1993) for middle school students, and can serve as a prototype for other graph tasks.

The task

Students were given a table and a time series plot containing information about the average time of sunset from June to December (see Figure 1). The task was presented in two parts. The first part required that the students, working alone, read the two displays of the data, think about the data individually for a few minutes, and write their interpretations of the given information.

Part 1:   Read the following two displays of information. Working alone, write as many things as you can about the information given.

AVERAGE TIME OF SUNSET

Month	Time
June	8:30 PM
July	8:25 PM
August	8:15 PM
September	7:40 PM
October	6:20 PM
November	5:20 PM
December	4:35 PM

Share your interpretation of the information with the members of your group. The recorder   of the group is to write a statement that represents the group's interpretation.

Part 2:   Work with the members in your group. Using the line graph entitled, "Average Time of Sunset," draw a picture of what the graph would look like if it were to continue from January to May.

Figure 1: The two parts of the graphing task

Successfully completing the task depends on students' awareness of changes in the amount of daylight hours during the different months of the year and relies on their everyday experiences for a reasonable solution.

After completing their individual written interpretations, students were organized into small groups of four to share their ideas and record their agreed upon interpretations. One student in the group was the recorder and kept a written account of the ideas.

For the second part of the task, as the students worked in the same small groups of four, they were asked to extend the graph by drawing a picture of what the graph would look like if it were to continue from January to May. This part of the task required students to recognize and discuss trends in the data, relate their experiential knowledge about the amount of daylight hours during the different months of the year to the task at hand, and integrate and translate this information into a time series plot for the remaining months of the year, January through May. The students' problem-solving behaviors on the task were recorded using a framework adapted from Artzt and Armour-Thomas (1992). A full description follows.

A FRAMEWORK FOR ANALYZING STUDENTS' PROBLEM-SOLVING BEHAVIORS

Polya's (1945) conception of mathematical problem solving as a four-phase heuristic process (i.e., understanding, planning, carrying out the plan, and looking back) has served as a tool for investigating problem-solving competence. More recently, these categories have been expanded and examined by researchers who have begun to identify the importance of metacognition in mathematical problem solving (e.g., Garofalo & Lester, 1985; Schoenfeld, 1987; Silver, 1987) and in assessing higher-order thinking in mathematics (Baker, 1990). These researchers identified monitoring and self-regulation as metacognitive behaviors that are crucial for successful problem solving in mathematics. Small problem-solving groups provide natural settings for discussion in which interpersonal monitoring and regulating of members' goal-directed behaviors occur. These may well be the factors that are responsible for the positive effects observed in small-group mathematical problem solving and so these are the factors that one would wish to encourage and assess as students participate in small mathematical problem-solving groups.

The results of a study that examined problem-solving behaviors within the context of small groups (Artzt & Armour-Thomas, 1992) suggest that the continuous interplay of cognitive and metacognitive behaviors that occurs among members of successful problem-solving groups mirrors the thoughts and behaviors of expert problem solvers working alone. Students working in small groups have the opportunity to communicate about mathematics as they discuss and develop problem-solving strategies.

Artzt and Armour-Thomas (1992) developed a framework for analyzing the interactions among the members of small groups. They argued that, as students work within a small group to solve a mathematics problem, their behaviors range from *talking about the problem* (a metacognitive behavior), to *doing the problem* (a cognitive behavior), to *watching or listening* to other students talking about or doing the problem. At times, some students may be *off task* and exhibit none of these behaviors.

In the remainder of this section we analyze in detail the many elements that may be part of these four general categories of such group problem-solving behaviors. This analysis is useful as

it outlines the range and diversity of behaviors, skills, and interactions that may have to be the subject of assessment efforts by teachers who want to promote effective group problem-solving by their students.

Below we explain how these four categories of group problem-solving behavior pertain to graph tasks in general and to the specific graphical task presented earlier. The framework below relates to observable behaviors but also remarks about possible underlying mental activities (mainly cognitive and metacognitive) and related problem-solving heuristics that presumably occur during the work process. In reading through our analysis, the readers are asked to assume that they are observing a group of students and have to record any observations on a form such as the one described in Figure 2 (and discussed in detail later on).

We should note that the order of categories below is not necessarily the sequence in which the problem-solving behaviors may occur. Several approaches or steps that could have been used to complete the task are also mentioned, in order to raise issues that go beyond the particulars of the task used in this chapter.

Talking about the problem

This category of behaviors is comprised of six possible types. Three are listed in this section: understanding, analyzing, planning. Three additional behaviors are listed later as comprising parts of "doing the problem": exploring, implementing, verifying; these may also be part of "talking about the problem," and can be considered as either cognitive or metacognitive, depending on the types of actions taken or statements made.

Understanding. This subcategory is indicated when students make comments that reflect attempts to clarify the meaning of a problem. In general, when students have to interpret or create a graph, they must understand what the axes represent and the relationship between variables (e.g., what are the independent and dependent variables). They must also be familiar with the meaning of and preferred uses of specific graphical representations (e.g., bar graph, stem-and-leaf plot, circle graph).

In our graphing task, the students must understand that a graph is to be drawn that extends through the remaining months of the year. They must understand that they have to do three things in order to complete the task:

1. A rectangular grid must be drawn.
2. The grid must have an x-axis containing the months, January, February, March, April, and May.
3. The y-axis must contain the average times of sunset, which they are to figure out.

Analyzing. This subcategory relates to moments when students make statements revealing that they are trying to simplify, reformulate, or analyze a problem. Reading between and beyond the data are reflected in such statements. In a general graphing task, students may recognize patterns or trends in the data. They may show that they are familiar with the context of the data and use their background knowledge or experiences to help make sense of what they read in the graph or what they will represent in the graph.

In our graphing task, the students may analyze the problem in the following ways:

1. Looking at the patterns from the given data they can notice a trend in the change of average time of sunset from one month to the next.
2. They can think about their personal experiences with sunset hours in the months from January through May.
3. They can think about what the average time of sunset might be if the pattern were to continue and compare that with their experiences.

Planning. This subcategory refers to cases when students make statements about how to proceed in the problem-solving process. In a task that requires an interpretation of a graph, they may decide to look for patterns or trends in the data. To create a graph, they may decide which variables belong to the appropriate axes. They may approximate appropriate ranges for the data and intervals to use. They may plan what type of graph they will use.

In our graphing task, if the students attempt to plan an approach for solving the problem, they may do the following (note that the plans might not be ones that will lead to a successful solution):

1. Draw a coordinate grid with the months from January through May across the x-axis.
2. List the average times of sunset on the y-axis. (The range of these times differs.)
3. Find the difference between each successive average time of sunset and look for a pattern in the differences.
4. Continue the pattern of differences to calculate the average time of sunset in the remaining months by subsequent subtractions.
5. Use the pattern of differences to create a pattern of subsequent additions to find the remaining average times of sunset.
6. Use personal experiences of all group members to get the remaining average times of sunset.

Doing the problem (or Talking about the problem)

This category is comprised of four types of behavior. The first, "reading," is predominantly cognitive (though of course involves metacognitive processes). The three remaining types, as mentioned above, may belong either in this category ("Doing") or in the previous one ("Talking"), depending on the types of actions taken or statements made. They can involve either cognitive or metacognitive processes.

Reading the problem. At some points students may read the problem or data or listen to someone else read. The metacognitive aspect of this reading behavior can only be recorded when students verbalize their understanding of what they have read.

Exploring the problem. Exploration as a cognitive activity alone often results in disorderly, aimless, and unchecked wanderings. When exploration is guided by the monitoring of either oneself or one of the group members, that behavior can be categorized as exploration with metacognition. Such monitoring leads to self- or group regulation of the exploration process, thereby keeping the exploration controlled and focused. For example, when students are called upon to interpret a graph they may mistakenly interchange the variables and come to an incorrect conclusion about the trend they notice. If they or their group members do not take the time to

consider whether their interpretation makes sense, they are exploring without metacognition. The same metacognitive behaviors are necessary when students embark on the creation of a graph without prior planning. Without monitoring, this exploratory form of graph creation can lead to improper use of axes, inappropriate intervals and range for variables, and the use of inappropriate graph types.

The graphing task lends itself to some guessing and testing because the differences in the data on successive months of average times of sunset do not form a consistent pattern. While the average time of sunset from June through December does steadily decrease, it does not do so in a discernible pattern. This means that students usually begin estimating what the continuation of the pattern could be. Without using monitoring, this exploration might lead to an incorrect continuation of the decrease in average time of sunset. Another unmonitored exploration might lead a student just to continue the line formed by the given graph. When monitored, these types of explorations could lead to students realizing that a change in direction must be made because their experiences do not support their results.

Implementing. At some points students may devise a plan for solving the problem, and may attempt to implement the plan. If the students perform this implementation systematically with monitoring and regulating (metacognitive), they are likely to discover that either the plan was good and has led to a reasonable solution, or it was faulty and needs some adjustment. If the implementation is unmonitored (i.e., cognitive level alone), however, students may follow through on the implementation leading to an incorrect and unreasonable solution.

Verifying. An effective verification requires students to examine their final response or solution and check that the answer makes sense (metacognitive). When interpreting a graph, students must compare what they think the graph is saying either to their knowledge of the individual pieces of data or to their life experience and knowledge about the data and its source. After having created a graph, they must check to see that the representation conforms to what they know to be true about the data.

In our graphing task, the students must determine whether the average times of sunset they have calculated are consistent with their personal observations of average times of sunset in the months of January through May. If they have tried to continue the pattern in the given data as it is, or in the reverse direction, they may try to verify (metacognitive) their results by checking their successive subtractions or additions (cognitive).

Watching and listening. These behaviors cannot be categorized as either cognitive or metacognitive because they are not audible. However, students must be willing and able to listen and watch each other in order for an exchange of ideas to take place.

Off-task behaviors. These behaviors cannot be categorized as either cognitive or metacognitive because they are not related to the problem-solving task.

Based on the framework described above, we have developed an instrument (see Figure 2) to aid us in our quest, as researchers, to understand the problem-solving behaviors of students as they work in small groups (Artzt & Armour-Thomas, 1992). Yet, teachers who have familiarity with problem-solving heuristics may readily use the instrument. A teacher could systematically examine the behavior(s) of each student in a group being observed for about one minute and note

the proper category or categories of behavior. Important anecdotal information that further describes the students' behaviors could be added at the bottom of the chart. For example, the teacher might wish to point out which students were responsible for making what Schoenfeld (1985) refers to as "executive decisions." These are the key decisions that can account for the success or failure of the group work, such as insightful plans for how to solve a problem, or the acute observation that the problem solution is going in the wrong direction.

	Talking About the Problem							Doing the Problem					Watching and Listening	Off-Task
Name of Student	U N D E R S T A N D I N G	A N A L Y Z I N G	P L A N N I N G	E X P L O R I N G	I M P L E M E N T I N G	V E R I F Y I N G		R E A D I N G	E X P L O R I N G	I M P L E M E N T I N G	V E R I F Y I N G			
Student A														
Student B														
Student C														
Student D														
Anecdotal Information														

Figure 2. The Assessment Instrument

ASSESSING THE STATISTICAL PROBLEM-SOLVING
BEHAVIORS OF STUDENTS

In order to assess problem-solving behaviors properly, a variety of evidence about student performance must be considered (NCTM, 1995). To get an enhanced picture of students' understandings, one can first assess students' individual work and then examine their within-group behaviors in light of that work. Very often, there may be a discrepancy between a student's level of performance when working alone and his/her level of performance when working within a group. When this occurs, the teacher must consider the effect the group is having on the student and make changes when necessary.

In our project, to determine children's levels of knowledge prior to beginning the group task, their written statements for the individual part of the graphing task (i.e., interpreting data) were examined in terms of the categories of *reading the data*, *reading between the data*, or *reading beyond the data*. As an example, below are responses from four fifth graders, Chuck, Dennis, Garin, and Razzie, about what they thought was communicated in the time series plot:

Garin: The graph shows the average time of sunset per month.
Dennis: October sunsets one hour later than November.
Razzie: In December the sun sets earlier.
Chuck: In the summer it gets darker later than the winter about a difference of 4 hours.

Garin's statement simply restates the title of the graph; it reflects *reading the data.* Dennis and Razzie use comparatives in their statements (i.e., "later than" and "earlier," respectively), reflecting *reading-between-the-data* comprehension. Chuck introduces "summer" and "winter" ideas into the graph; his statement reflects *reading-beyond-the-data* comprehension.

It is interesting to note that when the students were given the chance to share their ideas and agree on a group interpretation, they chose Chuck's statement, which reflected the highest level of comprehension. Specifically, Razzie, who volunteered to be the recorder wrote: "Everybody in this group agrees that the sun sets an estimate of four hours later in the summer than winter. "

For the second part of the graphing task (i.e., creating a sketch of a graph), the group was given one sheet of unlined paper with the following instructions:

Using the line graph about "Average Time of Sunset," draw a picture of what the graph would look like if it were to continue.

The children worked for approximately 15 minutes to complete the task. The first seven minutes of their problem-solving behaviors recorded by an observer can be found in Figure 3. To give the reader a frame for interpreting this chart, an overall picture of the group's problem-solving efforts is presented below. Examples of the specific events that contributed to the checks entered for each student are then described.

From Figure 3 it can be seen that during the first seven minutes of their group problem-solving session none of the children was off task; each of them at some time watched or listened to one another. However, although it seems apparent that each of the students was involved in the problem-solving process, the quality and quantity of their contributions varied. For example, Garin took the lead in solving the problem. He engaged in almost each type of problem-solving

behavior at both cognitive levels. That is, he was instrumental in coming up with ideas about how to do the problem and he participated in actually doing the problem.

Razzie, on the other hand, seemed to remain on the outskirts of the group solution. She made several efforts to try to understand what the problem was asking for, and aside from one instance of analyzing the problem, she remained in an exploratory cognitive phase. Chuck and Dennis were integrally involved in the solution of the problem. They were attentive to the ideas of all, as is evidenced by the multitude of instances in which they were watching and listening, and they both took part in analyzing the problem and implementing the ideas about how to approach the problem.

Name of Student	Talking About the Problem							Doing the Problem					Watching and Listening	Off-Task
	UNDERSTANDING	ANALYZING	PLANNING	EXPLORING	IMPLEMENTING	VERIFYING		READING	EXPLORING	IMPLEMENTING	VERIFYING			
Chuck	—	— —		—	— — — —			—		—			— — — — — — —	
Dennis		— — —		—	— — — —	—		—		— — —	—		— — — — — — — —	
Garin	— —	— —	— —	— — —	—	—		—		— — — —	—		— — — —	
Razzie	— — —	—		—				—	— —				— — — — — —	
Anecdotal Information														

Chuck, Dennis, and Garin were responsible for doing most of the problem solving while Razzie, for the most part, watched and listened. Garin was the only one who came up with several plans. Chuck, Dennis, and Garin all worked on implementing the plans. Chuck, through careful monitoring of the

implementation, made the important observation that, if they were to continue following the pattern they would arrive at an unrealistic solution. This observation caused Garin to revise the plan and set the problem solution on track.

Figure 3: Recordings of Problem-Solving Behaviors
During Small Group Work on Graphing Task

When examining some of the specific comments made by the students, one can get a greater understanding and appreciation for the contributions made by the students and the coding decisions made by the teacher.

Examples of reading and understanding the problem:

In the beginning of the group session, after reading the problem, several students could be heard trying to understand the problem. Razzie asked, "What do they mean to continue for all the months?" Garin asked, "No, but listen, how can you continue, it ends in December?"

Examples of analyzing the problem

The students then began to *analyze* the problem and arrive at some ideas. Garin said, "Maybe you have to start from January all the way through May." Dennis added, "There has to be some kind of pattern there so we could figure it out." Razzie noticed, "Check this out. Look, 5 minutes after in July the sun sets 5 minutes before it did in, um, June."

Examples of exploring the problem

To get better acquainted with the problem, the group got involved in a bit of *exploration*. Chuck said, "So wait, estimate the times here (pointing to the displays in center of the desk). 8:30, 8:00, wait a minute...It goes by half hours so just figure out like..." Razzie tried to complete Chuck's thought, "Chuck, 8:15, half an hour, a whole half an hour."

Returning to understanding and analyzing

Then they returned to trying to *understand* how to go about doing the problem. Chuck said, "Don't do it by this [the table], do it by the graph, it said the graph." Garin questioned, "We have to draw pictures, right?" After examining the data on the graph for a short while, Garin, Chuck, and Dennis engaged in further *analysis* of the problem. Garin stated, "Wait, see January starts a new year. See every month it goes down about an estimate of 15-20 minutes. OK, an estimate of 20 minutes. So if you get 8:30, if you do it 8:30 and you keep on subtracting 20 all the way up till January, you'll get your estimate." Chuck added, "The average time goes down about half an hour." Garin responded, "No it doesn't, look because..." Dennis interrupted, "No, if we're going down a half hour, this is 15 minutes and then you just have to keep going down." During this time Razzie was still trying to *understand* the problem. She asked, "Can I ask you a question? Are any of you sure what you're talking about?...Very sure?"

Examples of planning and further analysis of the problem

Finally, Garin announced a *plan* (although faulty), "So let's see, if you start in, in June, it's 8:30 and you keep subtracting maybe 20, keep on subtracting 20 you will probably get your answer for every month, maybe." But Dennis and Chuck were not about to accept the plan

without further *analysis.* Dennis noticed, "But look, this is 5 and the next one is 10. But then the next one is like no pattern." Chuck added a point of information, "In May it's like 9 o'clock." Dennis added, "There has to be some kind of pattern, but, between here is 5 and between here is 10."

Examples of implementing the plan

Despite the lack of evidence of a consistent pattern, Chuck, Dennis, and Garin began to *implement* Garin's plan for repeated subtractions. Luckily, Chuck was monitoring the implementation and made the important observation, "By the time we get to [inaudible] we're going to be down to like 3 o'clock. It gets dark at 3 o'clock? Be for real." Based on this statement, the boys began to make adjustments to their previous *implementation*. Dennis said, "No, because then you have to like start making the time go on higher." Garin responded, "Oh, that's right. It goes like this. Listen, 8:30, subtract, [pause] then it will probably go down." Dennis replied, "The difference in between the time gets larger and it also gets smaller. It starts decreasing." And Chuck adds again, "In May it gets dark at 9 o'clock."

Examples of making a new plan and final implementation

The above discussion sparked Garin to come up with a new *plan*. He suggested, "Look at this. Would you listen? Look it goes down every 5, 10, 35. So why don't you just do this--subtract there from 5 and do it like, this is like your middle number. You got it?" The group used the remaining time to implement this improved plan. As Razzie began to draw the grid, impatiently, Garin grabbed it from her to construct the graph. Chuck and Dennis closely monitored his work and Razzie looked on.

With detailed data from the individual and group efforts (of Chuck, Dennis, Garin, and Razzie, in our case), the teacher has access to a wealth of information to provide for thoughtful assessment. These kinds of data should be further evaluated to yield a more complete picture of students' level of statistical problem-solving. This integrative evaluation is discussed in the next section.

INTEGRATIVE ASSESSMENT

It is interesting to note that the results of both the individually agreed-upon interpretation of the sunset data and the completed group graph (see Figure 4) reflect the highest level of comprehension. That is, the statement that the students agreed on for a description of the data was Chuck's statement, "In the summer it gets darker later than the winter about a difference of 4 hours, reflecting reading beyond the data.

Overall, students' interaction appears to have brought the group to a level of reading beyond the data, illustrated in their final product in Figure 4. Contrasting the levels of comprehension of the students' individual statements with the problem-solving behaviors they exhibited when they worked within their small groups, however, reveals some consistencies as well as some inconsistencies.

In his individual work, Chuck was the only student who made a statement reflecting the highest level of cognitive performance--reading beyond the data. Similarly, within the group, he also performed at a high level. Not only was he actively engaged in all aspects of the problem-solving process, but he was the one who made the keen observation that following Garin's plan

would lead to a senseless solution. This is an example of the type of monitoring of a problem solution that is characteristic of expert problem solvers.

Dennis, when working on his own, made a comparative statement reflecting the ability to read between the data. His active involvement and understanding of the problem solution within the group showed a similar level of comprehension as that which he demonstrated while working alone.

Razzie made an attempt to make a comparative statement–reading between the data–when working on her own. Yet, she really did not seem to grasp the full meaning of the problem during her group work. She made several attempts at trying to understand what the problem was asking for, but as evidenced by what seemed to be her aimless explorations, she never attained more than a very low level of comprehension.

Figure 4: Solution to Graph Task

In his individual work, Garin was the only student who made a statement reflecting low level cognitive performance--reading the data. In extreme contrast, within the group he performed at a higher level than all of the students. That is, he had the greatest number and variety of metacognitive behaviors, and he was the only one who suggested any plans for how to approach the problem (see Figure 3).

The teacher and the students have much to learn from these results. For the teacher, instructional decisions may be made for individuals as well as for the group. For the students, reflecting on their problem-solving behaviors can reveal a great deal about their own strengths and weaknesses as individuals and as members of a group.

IMPLICATIONS

Two key purposes of assessment are to provide students with an accurate window into their emerging capabilities, and provide teachers with a broad picture about students that can help them make informed instructional decisions. The approach to assessment of a group problem-solving process described in this chapter can contribute information that can serve both the teacher and the students. Although only two sources of evidence were available in the assessment method described here (i.e., results of the individual and group parts of the graph task), additional sources of information are available to teachers (see other chapters in this volume) and should be incorporated into a holistic assessment of students' knowledge and performance.

Making Instructional Decisions

The approach to assessment illustrated in this chapter can and should serve as an integral part of instruction–helping teachers to make instructional decisions about content, grouping of students, events in one group that should be discussed by the whole class, and so forth. When teachers notice, for example, that metacognitive problem-solving behaviors such as regulating, monitoring, and checking occur within a group, they need to bring these behaviors to the attention of the class. An example is Chuck's important statement (see "Examples of implementing the plan" above) that caused his group to redirect its efforts.

Likewise, opportunities for children to recognize the importance of questioning the reasonableness of their problem-solving processes or solutions should be provided. For instance, Garin served as a rich source of ideas and suggested a strategy for implementing a plan, but this would have led to an unreasonable solution without Chuck's observation. Garin and the other students should be helped to realize that deficiencies in monitoring and checking may impede their problem-solving performance.

Teachers and students should be made aware that inconsistencies in students' individual and within group behaviors may occur, and need to be alert to the need to make adjustments in group formation. For example, a more suitable group assignment for Razzie should perhaps be sought as the group setting Razzie encountered in the group described here did not appear to contribute to her understanding of the task. Decisions about changing group assignments should be made, for example, based on the group's social and academic performance (Artzt, 1994).

The graph task presented to the fifth graders was both engaging and challenging for them. Based on their successful completion of the graphing task and their level of interest, the teacher may find it worthwhile to extend this experience. For example, a follow up activity may require that the students collect their own data about daily AM and PM temperature, average monthly precipitation, or accuracy of weather forecasts. At this point, students may be ready to design their own display (e.g., table, line graph), describe why they selected it and explain what information they expect to be able to extract from it. They could use graphing software to experiment with different types of displays, and compare the usefulness of the information each conveys.

Student self-assessment

Another way to use the results of the graphing task is to empower students by engaging them in the process of self-assessments (Paulu, 1994). Getting students to look at their own problem-solving abilities and behaviors when working alone or in groups supports their development as autonomous learners. To maximize students' awareness of their own problem-solving behaviors, the assessment method described here could be adapted for use by the students themselves. Information students record on it can later inform a group discussion focused on events or processes (in both the cognitive and metacognitive domains) that contribute to the final product. Such a discussion could explore the contribution of ideas suggested or actions taken by specific members of a group, as well as highlight the contribution of processes such as monitoring or questioning the reasonableness of solutions.

Through a self-assessment process, students can become more aware of their contributions to the group in comparison to their individual levels of comprehension. For example, it seems that Razzie may have had more to offer than what was exhibited in the group. It would have been useful for her to determine what was it about this particular group setting that caused her to become withdrawn. Garin, on the other hand, could benefit from reflecting on his somewhat impulsive approach to devising and implementing plans. He should be made aware of the importance of regulating and monitoring his behaviors. These issues, of course, are general and their resolution can contribute to students' general problem-solving skills.

In summary, it is important to reiterate that the time series plot used in this exploratory work is representative of many other graphs and plots with which students should become familiar (Curcio, 1989; Friel et al., in this volume; Macdonald-Ross, 1977). Graphical tasks in general lend themselves to higher-level problem-solving behaviors, as they challenge students to integrate, apply, and transform what they already know. The many substeps described earlier as being part of the process of solving a statistical problem in a group context are quite general, and many also pertain to individual problem solving. We have attempted to demonstrate how individual assessment techniques can be supplemented by techniques that monitor students' problem-solving behaviors as they work within small groups, to yield rich information that can

inform instructional decisions. As educators now realize, using multiple sources of evidence about students' strengths and weaknesses provides a more complete picture of their capabilities (NCTM, 1995).

It is not yet clear how interacting in small groups helps improve individual statistical problem-solving ability. Yet, it is clear that by using an assessment instrument that places value on higher-level problem-solving behaviors, students are more likely to be sensitized to the importance of higher-level cognitive and metacognitive processes, and can be enlightened about techniques for improving their own individual graph comprehension. Assessment techniques that focus on group processes and behaviors can potentially provide students and teachers alike with a wealth of rich information about ways to improve statistical reasoning skills.

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