Do Your Students Measure Up

How are the results of the Third International Mathematics and Science Study (TIMSS) connected with your classroom? How would your students perform on these questions? How can you help your students perform well on questions like these? Do your students measure up metrically?

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The Third International Mathematics and Science Study showed promising results for third- and fourth-grade students tested in the United States (U.S.). Students in the United States scored higher than the international average in all but one content category. These results are in sharp contrast with the eighth- and eleventh-grade results, which show that U.S. students scored lower than the international average.

In the third- and fourth-grade results, the only content category in which scores for the United States were below the international average was Measurement, Estimation, and Number Sense. We examined the released items from this content category to better understand the reasons for this deficiency. Our study revealed that six of the eleven released test items in this category involved the metric system. These six metric items, as well as the percents of students who responded correctly to each item, are shown in **table 1.**

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An initial review shows that two of the six questions, items K7 and L6, were based on concepts that are independent of the system of measurement. The U.S. students performed at about the international average on both of these questions. On three of the remaining four questions that required knowledge of the metric system, the U.S. children did rather poorly. We wondered why questions involving the metric system pose such a serious challenge to U.S. students. Although the answer to this question is not simple, the opportunity to experience the metric system in and out of school is a major factor.

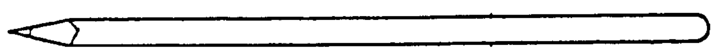
Local Opportunities

Efforts have been made dating back to Thomas Jefferson to adopt the metric system in the United States, but among countries participating in TIMSS, it is the only one that does not use the metric system in everyday experiences (International Association for the Evaluation of Educational Achievement 1997). Despite this absence of metric units in everyday experiences, developing conceptual understanding of the basic units of the metric system has long been a goal of K–12 mathematics programs (Inskeep 1976; NCTM 1989; NCTM 2000). For this reason, TIMSS representatives for the United States decided to keep all appropriate questions in metric units. To study how the metric system is being presented in U.S.

Metrically?

TABLE 1

Released metric items from the TIMSS test and results

Test Item	Percent of Students Responding Correctly Internatioal Average	 United States Average
J6. Which of these is largest? A. 1 kilogram B. 1 centigram C. 1 milligram D. 1 gram	3rd grade: 61 4th grad: 72	3rd grade: 50 4th grad: 61
K5. About how long is this picture of a pencil? A 5 cm B. 10 cm C. 20 cm D. 30 cm 	3rd grade: 69 4th grade: 77	3rd grade: 46 4th grade: 55
K7. A thin wire 20 cemtimeters long is formed into a rectangle. If the width of this rectangle is 4 centimeters, what is its length? A. 5 centimeters B. 6 centimeters C. 12 cemtimeters D. 16 centimeters	3rd grade: 21 4th grade: 23	3rd grade: 25 4th grade: 23
L6. The weight (mass) of a clothespin is 9.2 g. Which of these is the best estimate of the total weight (mass) of 1000 clothespins? A. 900 g B. 9,000 g C. 90,000 g D. 900,000 g	3rd grade: 41 4th grade: 52	3rd grade: 38 4th grade: 52
M7. Which of these would most likely be measured in milliliters? A. The amount of liquid in a teaspoon B. The weight (mass) of a pin C. The amount of gasoline in a tank D. The thickness of 10 sheets of paper	3rd grade: 30 4th grade: 38	3rd grade: 33 4th grade: 38
V5. How many millimeters are in a meter? Answer:____________	3rd grade: 31 4th grade: 49	3rd grade: 11 4th grade: 22

Percents are recorded in boldface type for those items on which the average U.S. scores were significantly lower than the international average.

elementary schools in 1999, we collected data on the third- and fourth-grade mathematics programs from a midwestern school district.

In the district's third- and fourth-grade curriculum guides, the metric system is mentioned but not emphasized. According to the third-grade guide, students are to learn about liters, as well as cups, quarts, pints, and gallons, and be able to measure to the nearest centimeter and the nearest inch. The fourth-grade guide indicates that students should learn how to use both U.S. customary and metric units for linear measurement in real-life situations. This focus on real-life situations, however, may explain why the SI (metric system, from the French name *Le Système International d'Unités*) is not heavily emphasized either in the adopted textbooks or by the teachers themselves.

From our examination of the district's third- and fourth-grade mathematics textbooks, we could not determine that a student who completed this material would recognize that metric units are intended for everyday use. For that matter, the students may not understand important connections between U.S. customary and SI measurement. For example, the third-grade textbook has a ten-lesson unit on measuring using U.S. customary units, to be completed in twenty to thirty days. In contrast, the book has a two-lesson section covering the metric system, to be completed in five to seven days. In addition, U.S. customary units are integrated throughout the fourth-grade textbook, but metric units are mostly restricted to three sections that focus on SI measurement.

Surveys were distributed to 110 third- and fourth-grade teachers to inquire about the use of metric measurement in the classroom. Of the 28 third-grade and 30 fourth-grade teachers who responded, over 90 percent stated that their textbooks contain lessons about the metric system. Most of those who responded stated that they used metric units mainly for measuring length; only a few used metric units for measuring capacity or weight. Others responded that metric units received greater emphasis in science lessons than in mathematics, particularly in lessons linked with a science unit involving plant growth.

In summary, in the third and fourth grades, the metric system is treated as an introductory topic at best. When the subject is introduced in the third grade, linear measurement is the most common focus. The early grades do not emphasize deeper development of conceptual understanding or the acquisition of a broader knowledge base. Although we must be careful when making generalizations from one district, it seems safe to say that the metric system is not an integral part of U.S. students' daily experience and, therefore, is not viewed as essential in comparison with the U.S. customary system. This generalization is reflected in the district's curriculum, textbooks, and classroom instruction.

FIGURE 1

The Mars Climate Orbiter story

Mars Climate Orbiter Team Finds Likely Cause of Loss

September 30, 1999: A failure to recognize and correct an error in a transfer of information between the Mars Climate Orbiter spacecraft team in Colorado and the mission navigation team in Califorrnia led to the loss of the spacecraft last week, preliminary findings by NASA's jet Propulsion laboratory internal peer review indicate.

"People sometimes make errors," said Dr. Edward Weiler, NASA's Associate Administrator for Space Science. "The problem here was not the error, it was the failure of NASA's systems engineering, and the checks and balances in our processes to detect the error. That's why we lost the spacecraft."

The peer review preliminart findings indicate that one team used English units (e.g., inches, feet and pounds) while the other used metric units for a key spacecraft operation. This information was critical to the maneuvers required to place the spaccraft in the proper Mars orbit.

Source: science.m?is.naasa.gov/newhome/headlines/as30sept99_2.htm

Why Should We Be Concerned?

Although various attempts have been made to adopt the metric system in the United States (Clason 1977), public resistance has been too strong. Why, then, should we be concerned that our students do not know the metric system? Headlines from across the nation in September 1999 offer a strong argument for that need (see fig. 1). The Mars Climate Orbiter, a spacecraft costing $125 million, was lost because a contractor had used U.S. customary (English) units instead of metric units. This incident is not an isolated one. In 1983, a Canadian airplane almost crashed because its refueling amount was measured in pounds rather than kilograms, an error that made the fuel supply less than half of what was expected. Products that are made in the United States commonly use parts that are made in other countries, nearly all of which use metric measurement. The U.S. economy is no longer national but international, meaning that foreign markets are essential to the success of its businesses. U.S. students must be ready to compete in this international and, hence, metric environment.

What Can We Do?

Children who learn that the metric system is merely a measuring tool to be used on special occa-

FIGURE 2

"The golden rules"

Goal: To explore the relationships among centimeters, decimeters, and meters and to focus on multiple ways of reporting a single measurement.

Materials: Metersticks, decimeter sticks (a 1-cm-by-10-cm rectangle), and centimeter sticks (1-cm-by-1cm square). The sticks can be made from centimeter grid paper.

Directions:

1. Introduce the sticks as bars of gold. Ask students to compare the bars and establish the relationships among them. Identify the names of the stick as meter bars (m), decimeter bars (dm), and centimeter bars (cm) by having students measure each. Ask them to extend the relationships to the next smallest unit (mm).

1 dm = 10 cm = 100mm

1m = 10dm = 100cm = 1000mm

2. Distribute varying amounts of centimeter bars. The students are to trade centimeter bars for a decimeter bar if they have more than ten. Emphasize the importance of getting a fair trade. Have the students record their transactions in tables similar to the ones shown below. After a few rounds, repeat the activity with decimeter and meter bars. Also, reverse the process, going from the right-hand numbers to the left-hand numbers. For a real challenge, have students go from more than 100 centimeters to both decimeters and meters, and the reverse.

cm bars		dm bars	cm bars
43	=	4	3
78		7	8

dm bars		m bars	dm bars
37	=	3	7
89		8	9

sions are missing an important and exciting mathematical experience. The relationships among units in the metric system offer a rich context from which a multitude of mathematical concepts and connections can be developed. To assess the role that the metric system plays in your curriculum and classroom instruction, we offer the following three recommendations.

Recommendation 1

Assess what your students know about the metric system. Give your students the six TIMSS items shown in **table 1.** Of course, you should feel free to supplement these items with additional questions that assess students' conceptual knowledge of length, capacity, and mass. For some examples, visit the TIMSS Web site at **timss.bc.edu**, which includes the metric items and is a source of all released TIMSS items.

Recommendation 2

Check your students' level of sensitivity to the use of metric units in everyday life. With what uses of metric units are they familiar? Although the metric system may not be widely visible in the United States, various metric units are found on food packaging, for instance, the capacity on a 2-liter bottle of soda or the grams of fat on a label. Have your students noticed that a car's speedometer also shows kilometers per hour? Have they participated in a 5K run or walk?

Recommendation 3

Assess your curriculum and instruction, including both the district curricula and textbooks and your presentation of the metric system in your class. Do you use grams and liters as often as you do pounds and gallons? What do you do to develop your students' "measurement sense" with regard to the metric system? Do you help the students make connections between the metric and U.S. customary systems, for example, that a liter is slightly more than a quart? Does your use of the metric system involve actual measurement? Do you use the metric system as a mathematical context to explore other mathematics? Do you use real-world applications of the metric system in assessment, as well as in instruction?

After you have assessed your students' understanding and the metric skills and concepts that your curriculum delivers, you must decide whether you are satisfied with what you have discovered. If you are satisfied, keep doing what you are doing. If you are not satisfied, a new challenge awaits you: to form and implement strategies that will help your students develop a full conceptual understanding of the metric system and the multitude of mathematical connections that lie within it. That is, make a plan that will help your mathematics program measure up metrically!

A Few Metric Activities

Many activities can be incorporated into the curriculum throughout the year to develop benchmarks for metric units and explore relationships in the metric system. The following three activities are offered as examples of how such connections can be developed. The first activity, "the golden rules" (see fig. 2), uses the context of trading bars of gold to encourage an exploration of the relationships among centimeters, decimeters, and meters. This activity also offers opportunities to focus on multiple ways of reporting a single measurement and to make meaningful connections with place value. In fact, this exploration can be the launching point of a discussion of decimals and the natural extension of the base-ten number system to include decimals.

The second activity, "getting to know 1 kilogram" (see fig. 3), is designed to help students develop benchmarks for metric units. This activity uses a common material, sand, to establish a benchmark for a kilogram. The students build more benchmarks by searching the room for other objects with a mass of approximately 1 kilogram and making conjectures about the mass of other items. Such benchmark-building activities are natural starting points from which to explore the estimation of measurements.

The final activity, "water works" (see fig. 4), builds on a common benchmark with which all our students are familiar, a 2-liter bottle. This activity, however, is specifically designed to help students build an understanding of the connections among grams, liters, and meters; that is, that 1 liter of water, when measured at a certain temperature and altitude, is 1000 cubic centimeters and has a mass of 1 kilogram. The connections made by the students in this activity should reinforce the understanding built by conversion and benchmark-building activities, such as "the golden rules" and "getting to know 1 kilogram." These activities and the resources listed below are starting points for you to help your students measure up metrically!

References

Clason, Robert G. "1866: When the United States Accepted the Metric System." *Arithmetic Teacher* 24 (January 1977): 56–62.

Inskeep, James E. Jr., "Teaching Measurement to Elementary School Children." In *Measurement in School Mathematics*. 1976 Yearbook of the National Council of Teachers of Mathematics (NCTM), edited by Doyal Nelson and Robert Reys, pp. 60–86. Reston, Va.: NCTM, 1976.

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National Council of Teachers of Mathematics (NCTM). *Curriculum and Evaluation Standards for School Mathematics*. Reston, Va.: NCTM, 1989.

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FIGURE 3

"Getting to know 1 kilogram"

Goal: Tu use familiar objects to establish benchmarks for 1 kilogram

Materials for each group: water, plastic 2-liter cola bottles with caps, balances (check with your science specialist if you do not have these in your classroom), metric weights.

Directions:

1. Place an empty 2-liter bottle on one side of the balance, and use metric weights to find its mass. It is probably negligible.
2. Add a 1-kilogram weight to the side of the balance containing the weights.
3. Add sufficient water to the bottle to balance the beam. The bottle should be approximately half full. Cap the bottle.
4. Have the sudents find objects in the room that have approximately the same mass as this 1 kilogram bottle of water.
5. Have the students recod these objects as benchmarks for 1 kilogram.
6. Several days later, ask students about things they remember that have a mass of about 1 kilogram.

FIGURE 4

"Water Works"

Goal: To establish connections among units in the metric system

Materials for each group: A 2-liter bottle filled with water, a pitcher (or any container that will hold 1 liter), a 1-liter cube container with open top and dimensions of 10 cm by 10 cm by 10 cm, a pan or container that is large enough to hold the cube and catch spills, a metric scale that is accurate enought to measure 1 kg.

Directions for each group:
1. Weight the empty pitcher, and record the result.
2. Measure the length, width, and height of the interior of the cube to the nearest centimeter, and record the results.
3. Pour water from the 2-liter bottle into the cube container, keeping the pan under the container to catch spills.
4. Empty the container into the pitcher.
5. Pour the remainder of the water from the bottle into the cube.
6. Record the number of liters that the cube contains. (Because the 2-liter bottle has just enought contents to fill the cube twice, the students should now be convinced that both the pitcher and the cube contain 1 liter of water.)
7. Next, weight the pitcher with the water and record the result. Subtract the mass of the empty pitcher from the mass of the pitcher with water, and record the mass of 1 liter of water.

After the small-group work:
8. As a class, display each group's data on the board, Ask the students to identify the relationship among the liter, the centimeter, and the kilogram. Make sure to emphasize the central role of water in these relationships.
9. If your class has worked with multiples of 10, you may want to split the students into three groups. Have group A describe the relationshop between the meter and the liter, have group B describe the relationship between the liter and thr gram, and have group C describe the relationship between the gram and the meter.
10. Have the groups present their relationships to the class.

TIMSS International Study Center. timss.bc.edu. World Wide Web.

Resources for Metric Regulations and Standards

National Institute of Standards and Technology (NIST) "Metric Program Pages." ts.nist.gov/ts/htdocs/200/202/mpo_home.htm. World Wide Web.
———. "Fact Sheet on Metric Labeling for Consumer Packages." ts.nist.gov/ts/htdocs/230/235/metric.htm. World Wide Web.
"NCTM Position Statement on Metrication." nctm.org/about/position_statements/position_statement_09.htm. World Wide Web.
U.S. Metric Association. "Go Metric." lamar.colostate.edu/~hillger/. World Wide Web.

Resources for Additional Metric Lessons

From Here to There with Cuisenaire Rods. Palo Alto, Calif.: Dale Seymour Publications, 1997.
Activity book that focuses on area, perimeter, and volume and that can be used for metric units of study.
Key to Metric Measurement. Berkeley, Calif.: Key Curriculum Press, 1998.
Set of four books on length, perimeter, area, volume, mass, capacity, temperature, and time.
Measurement in the Middle Grades. Addenda Series, Grades 5–8. Reston, Va.: National Council of Teachers of Mathematics, 1994. ▲

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