Using PISA to Stimulate STEM Teacher Professional Learning in the United States: The Case of Mathematics

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Contemporary interest in STEM education is fueled, in part, by the poor performance of U.S. students on national and international assessments. According to a recent National Research Council (2011) report on STEM education in the United States, the National Assessment of Educational Progress (NAEP) indicates that approximately 75% of U.S. 8th graders are not proficient in mathematics when they complete 8th grade, and, despite some progress over time, significant achievement gaps between racial and socioeconomic status subgroups persist in NAEP performance. Performance data also typically indicate lower levels of average performance in mathematics and science for U.S. students than for their counterparts in other countries with whom the United States competes in the global marketplace of commerce and information. For example, only 10% of U.S. 8th graders met the Trends in International Mathematics and Science Study advanced international benchmark in science, compared with 32% in Singapore and 25% in China (Gonzales et al., 2008). The central premise of this article is that at least one international assessment of mathematics and science, the Programme for International Student Assessment (PISA), is valuable for reasons that

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go well beyond its use as a source of data; it sounds the alarm about low U.S. student achievement and, thus, motivates greater attention to STEM education.

Triggered by the reported low levels of performance on domestic and international assessments of mathematics and science learning, much of the public policy conversation about the importance of STEM education focuses on the need to produce a cadre of well-prepared high school graduates. These students will, in turn, become the college graduates who qualify for demanding jobs in STEM-related fields to keep the United States competitive in the global economy. Nevertheless, even if the STEM initiatives now underway in the United States to increase the number of students eligible to enter STEM-related careers are successful in their quest, the fact remains that the vast majority of precollege and college students in this country will not be employed in STEM fields when they complete their schooling. One influential report from the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2011) eloquently captures this reality:

> The primary driver of the future economy and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering. . . . 4 percent of the nation's workforce is composed of scientists and engineers; this group disproportionately creates jobs for the other 96 percent. (p. 4)

Given this reality, why press for a broad-based approach to enhanced student learning in STEM fields? One reason is that recognition of the importance of literacy in mathematics and science predates the identification and naming of STEM as an integrated concept. For example, a focus on quantitative literacy has been advocated for the mathematics domain for over a decade (e.g., Madison & Steen, 2003; Steen, 2001), and Feinstein, Allen, and Jenkins (2013) make a similar argument for science: "Schools should help students access and interpret the science they need in response to specific practical problems, judge the credibility of scientific claims based on both evidence and institutional cues, and cultivate deep amateur involvement in science" (p. 314). An integrated exposure to STEM fields can cultivate in students, even those who do not pursue STEM-intensive careers, curiosity and passion that support a lifelong learning trajectory.

Students also will benefit from STEM literacy in other facets of their lives. As an NRC report on STEM education noted, "Individual and societal decisions increasingly require some understanding of STEM, from comprehending medical diagnoses to evaluating competing claims about the environment to managing daily activities with a wide variety of computer-based applications" (National Research Council, 2011, p. 3). High school and college graduates alike are called upon to participate in the democratic political process that is the hallmark of American citizenship. In that role, they participate in public debates and decisions about such issues as water quality and access, resource renewal in the face of global warming, and health care costs and quality. They also vote in elections that affect many STEM-related public policy issues, including those that influence local school boards and the U.S. Congress thereby shaping local and national investment in STEM education, research, and development. Additionally, they are likely to be the parents of many of the succeeding generations of potential contributors to the STEM enterprise. Thus, we think that it is important to consider all students, not only the mathematically and scientifically talented, as intended beneficiaries of increased attention to STEM education.

This "STEM for All" perspective makes clear the critical need to ensure that all students in our schools and colleges become STEM literate. From this perspective, we believe that PISA is an especially valuable resource for mathematics and science educators. If used appropriately, PISA can help promote the professional learning of U.S. teachers, thereby improving STEM teaching and learning in this country.

PISA's focus on literacy—the ability to use and apply knowledge and skills to real-world situations encountered in adult life—in mathematics and science is aligned with STEM literacy and thus appears to be exactly the right emphasis to achieve the "STEM for All" goal. In this article, we focus primarily on the STEM discipline of mathematics, but we think that our proposal that PISA can be a valuable tool to support this endeavor also could be applied to the science and engineering domains of STEM, and we invite interested readers to consider that possibility.

The PISA Assessment

PISA is an international assessment of 15-year-old students' reading, mathematics, and science literacy. PISA also includes measures of general or cross-curricular competencies, such as problem solving. PISA emphasizes functional skills that students have acquired as they near the end of compulsory schooling, as opposed to curriculum-based knowledge and skills.

PISA is coordinated by the Organization for Economic Cooperation and Development (OECD), an intergovernmental organization of industrialized countries, and is conducted in the United States by the National Center for Education Statistics. PISA was first administered in 2000 and is conducted every three years. The most recent assessment was in 2012.

PISA Frameworks

The frameworks guiding the PISA assessments reflect a consensus across OECD countries regarding the skills and abilities that demonstrate literacy in each content area. In 2012, mathematical literacy was defined follows:

> Mathematical literacy is an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognize the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens. (OECD, 2013, p. 25)

The PISA 2012 mathematical literacy framework consisted of three main components: (1) mathematical processes and underlying fundamental capabilities, (2) mathematical content, and (3) mathematical contexts (OECD, 2013). The process component encompasses much of what is commonly referred to as mathematical problem solving, including attention to (a) formulating situations mathematically; (b) employing mathematical concepts, facts, procedures, and reasoning; and (c) interpreting, applying, and evaluating mathematical outcomes. The PISA framework also identifies seven "fundamental mathematical capabilities" (e.g., communicating, representation, reasoning and argument, using mathematical tools) that underlie the processes and that are akin to the mathematical practices in the *Common Core State Standards* (Common Core State Standards Initiative, 2012) and the mathematical process standards in *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000).

The mathematics content assessed in PISA is defined by four overarching ideas: quantity, space and shape, change and relationships, and uncertainty. Within each content area, specific mathematical topics are delineated. For example, the area of change and relationships encompasses types of growth (e.g., linear, exponential, periodic, logistic) and relationships among types of growth; and the area of uncertainty includes probability, inference, and data collection/analysis/representation.

PISA places heavy emphasis on authentic uses of mathematics and thus includes tasks that embed mathematics in contexts that might be encountered in real-world situations. Four types of situations or contexts are defined and used in developing the problems in PISA: personal, occupational, societal, and scientific.

Key Features of PISA Tasks as Stimuli for Teacher Professional Learning

PISA tends to be less well known in the U.S. education community than some other large-scale assessments, such as NAEP and Trends in International Study of Mathematics and Science (TIMSS), which have been with us for a longer time. Yet, several features of PISA make it a potentially useful resource for mathematics teacher education:

1. PISA is relevant at both the middle school and secondary school levels. PISA is designed for and administered to a sample of 15-year-old students, an important point on the age/grade continuum, as content is likely to be highly relevant to teachers across the spectrum of grades 6-10.

2. PISA treats commonly taught content in novel ways. PISA tests mathematical ideas that are likely to be at the core of the mathematics curriculum in grades 6-10. A comparison of the 2003 versions of NAEP, TIMSS, and PISA found that the mathematics topics addressed in all three tests were quite similar, but PISA is substantially different in how knowledge is assessed, especially with respect to applied problem solving (Neidorf, Binkley, Gattis & Nohara, 2006). Thus, the way that the mathematics content is represented in PISA tasks is likely to be atypical for mathematics teachers, especially secondary school teachers, making it likely that PISA tasks can serve well as stimuli for teacher inquiry and reflection.

3. PISA focuses on quantitative literacy. PISA is intended to assess what some have called quantitative literacy (e.g., Madison & Steen, 2008), namely, students' ability to use and apply mathematical knowledge and skills to authentic problem-solving situations or contexts encountered in adult life. Thus, the PISA tasks do not generally mirror standard mathematics textbook exercises, and teachers are likely to view the PISA tasks as embodying a novel form of mathematical proficiency.

4. PISA tasks are cognitively complex. PISA's focus on complex thinking and problem solving in real-world application contexts makes it a good source of intellectually rich tasks for mathematics teachers to consider. An examination of the cognitive complexity of mathematics questions on three major assessments (PISA, NAEP, and TIMSS) found that PISA items were more likely than those on the other tests to be cognitively demanding (Neidorf et al., 2006). Another comparative analysis of PISA 2003 and TIMSS 2003 found that more than one-half of the PISA mathematics questions were classified as problem-solving tasks, the most cognitively complex category in the study, as opposed to less than one-third of the TIMSS questions (Dossey, McCrone, & O'Sullivan, 2006).

Illustrative PISA Tasks

To illustrate these features, we include two publicly released PISA items, which are embedded in contexts that also may be of relevance to science educators. Both pertain to mathematics taught across a range of grades. The Power of the Wind (POW) task (Figure 1), for example, involves students' computing basic calculations, solving an algebraic equation, and using the Pythagorean theorem. The juxtaposition of these topics in a single test item and the nonstandard question types found in the POW item also illustrate PISA's atypical treatment of commonly taught mathematical content. The POW task requires quantitative literacy in

Figure 1: Sample PISA Task: Power of the Wind

POWER OF THE WIND

Zedtown is considering building some wind power stations to produce electricity.

The Zedtown Council gathered information about the following model.

Model:	E-82
Height of tower:	138 metres
Number of rotor blades:	3
Length of one rotor blade:	40 metres
Maximum speed of rotation:	20 rotations per minute
Price for construction:	3 200 000 zeds
Turnover:	0.10 zeds per kWh generated
Maintenance cost:	0.01 zeds per kWh generated
Efficiency:	Operational 97% of the year

Note: kilowatt hours (kWh) is a measure of electrical energy.

Question 1: POWER OF THE WIND *PM922Q01*

Decide whether the following statements about the E-82 wind power station can be deduced from the information provided. Circle "Yes" or "No" for each statement.

Statement	Can this statement be deduced from the information provided?
The construction of three of the power stations will cost more than 8 000 000 zeds in total.	Yes / No
The maintenance costs for the power station correspond to approximately 5% of its turnover.	Yes / No
The maintenance costs for the wind power station depend on the amount of kWh generated.	Yes / No
On exactly 97 days a year, the wind power station is not operational.	Yes / No

Question 2: POWER OF THE WIND *PM922Q02*

Zedtown wants to estimate the costs and the profit that would be created by constructing this wind power station.

Zedtown's mayor proposes the following formula for estimating the financial gain, F zeds, over a number of years, y, if they build the E-82 model.

$$F = \underbrace{400\,000\,y}_{\text{Profit from the yearly production of electricity}} - \underbrace{3\,200\,000}_{\text{Costs of building the wind power station}}$$

Based on the mayor's formula, what is the minimum number of years of operation required to cover the cost of construction of the wind power station?

A. 6 years
B. 8 years
C. 10 years
D. 12 years

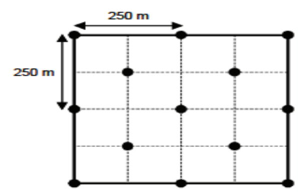
Question 3: POWER OF THE WIND *PM922Q03 – 0 1 9*

Zedtown has decided to erect some E-82 wind power stations in a square field (length = breadth = 500 m).

According to building regulations, the minimum distance between the towers of two wind power stations of this model has to be five times the length of a rotor blade.

The town mayor has made a suggestion for how to arrange the wind power stations in the field. This is shown in the diagram opposite.

Explain why the town mayor's suggestion does not meet the building regulations. Support your arguments with calculations.



● = wind power station tower
Note: Drawing is not to scale.

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....

....

Question 4: POWER OF THE WIND *PM922Q04 – 0 1 2 9*

What is the maximum speed that the ends of the rotor blades for the wind power station move? Describe your solution process and give the result in **kilometres per hour** (km/h). Refer back to the information about the E-82 model.

....

....

....

....

....

Maximum speed: .... km/h the form reading and interpreting numerical information, especially in question 1.

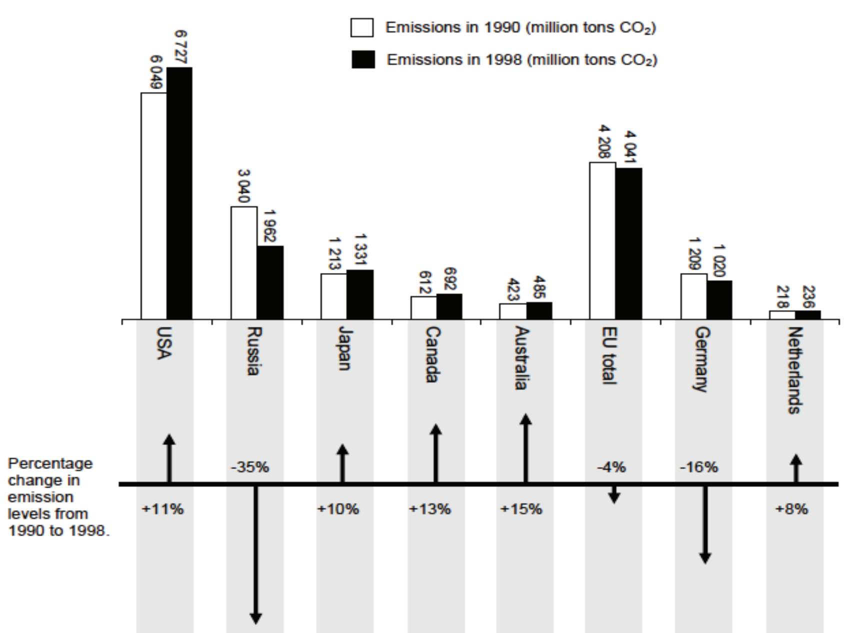
The Decreasing CO_2 Levels (DCL) task (Figure 2) also poses a nonstandard task: Instead of asking students to calculate a percentage change, they are asked to demonstrate how a particular change was obtained. This item illustrates PISA's focus on quantitative literacy, as it presents a unique and contextualized graph to read and interpret. This graph is an atypical blend of standard graphs that students typically learn to use in isolation from each other in mathematics classes.

Figure 2: Sample PISA Task: Decreasing CO_2 Levels

M525: Decreasing CO_2 Levels

Many scientists fear that the increasing level of CO_2 gas in our atmosphere is causing climate change.

The diagram below shows the CO_2 emission levels in 1990 (the light bars) for several countries (or regions), the emission levels in 1998 (the dark bars), and the percentage change in emission levels between 1990 and 1998 (the arrows with percentages).



Typical of many PISA items, POW and DCL are cognitively complex tasks. Both involve multiple representations and several calculations, translation between problem context and mathematical models, reasoning and interpretation, and precise communication skills (e.g., reading and interpreting quantitative information, expressing reasons and justifications for claims, and evaluating one's own answer or that proposed by another). For example, POW question 1 involves calculations, but students are not simply calculating. Rather, they are asked to draw on underlying mathematical knowledge to determine whether statements and calculations proposed by others are correct. Similarly, question 4 requires a complex calculation that involves circumference, rates, and changing units. In DCL question 3, students are required to think about two different unstated possible ways to determine an increase and to find the maximum value using each method.

Figure 2: Continued

Question 1: DECREASING CO_2 LEVELS *M525Q01 - 0 1 2 9*

In the diagram you can read that in the USA, the increase in CO_2 emission level from 1990 to 1998 was 11%.

Show the calculation to demonstrate how the 11% is obtained.

Question 2: DECREASING CO_2 LEVELS *M525Q02 - 0 1 9*

Mandy analysed the diagram and claimed she discovered a mistake in the percentage change in emission levels: "The percentage decrease in Germany (16%) is bigger than the percentage decrease in the whole European Union (EU total, 4%). This is not possible, since Germany is part of the EU."

Do you agree with Mandy when she says this is not possible? Give an explanation to support your answer.

Question 3: DECREASING CO_2 LEVELS *M525Q03 - 0 1 2 9*

Mandy and Niels discussed which country (or region) had the largest **increase** of CO_2 emissions.

Each came up with a different conclusion based on the diagram.

Give two possible 'correct' answers to this question, and explain how you can obtain each of these answers.

Using PISA to Stimulate Teacher Professional Learning: The UPDATE Project

Using PISA to Develop Activities for Teacher Education (UPDATE) is a project in which we have been exploring some potential uses of PISA tasks and data. We posit that PISA can be useful in much the same way as NAEP, which has long served as a key source of information for the U.S. mathematics education community. In UPDATE, we have developed some prototype, PISA-based materials and partnered with other professionals to use the materials in initial teacher preparation settings and teacher professional development contexts with teachers of mathematics in grades 6-11.

Experience with NAEP suggests that the tasks used in complex, comprehensive mathematics assessments can be useful to educators. Some NAEP-based articles have focused on individual assessment tasks (e.g., Blume, Zawojewski, Silver, & Kenney, 1998; Kenney, Zawojewski, & Silver, 1998) or clusters of related tasks (e.g., Kenney & Silver, 1997; Stylianou, Kenney, Silver, & Alacaci, 2000) that afford an opportunity for teachers to "go deep" into issues tied directly to classroom instruction and learning. Another approach has examined tasks and student performance with respect to a crosscutting issue of interest to teachers, such as equity (McGraw & D'Ambrosio, 2006; Silver, Strutchens, & Zawojewski, 1997; Strutchens & Silver, 2000) or mathematical problem solving and related processes (e.g., Silver, Alacaci, & Stylianou, 2000; Silver & Carpenter, 1989).

To illustrate what might be possible with PISA tasks, we briefly describe the use of a PISA item, M136: Apples, successfully used in a mathematics professional development setting. The Apples task is one of 50 publicly released PISA tasks after the 2006 assessment (http://www.oecd.org/pisa/38709418.pdf).

Using the Apples Task in Teacher Professional Development

The Apples task was used in the Developing Excellence in Learning and Teaching Algebra (DELTA) project, a mathematics teacher professional development initiative in Michigan that focuses on building curricular coherence across grades 6-11 in the treatment of topics associated with algebra. We partnered with the DELTA project to provide a context in which to test the materials that we were developing in the UPDATE project. Silver and Suh (in press) provide a detailed account of the DELTA project and the use of the Apples task in the project. Interested readers can find more information there than we can provide here, where we summarize some of the ways in which the Apples task was used to stimulate teacher professional learning.

The DELTA variant of the Apples task (Figure 3) incorporated two modifications of the original PISA task. The phrase “pine tree” was used instead of conifer, and the wording of question 3.2 was modified. In the original PISA Apples task, the wording of question 3.2 reads as follows:

> There are two formulae you can use to calculate the number of apple trees and the number of conifer trees for the problem described above:
>
> Number of apple trees = n^2
>
> Number of conifer trees = $8n$
>
> Where n is the number of rows of apple trees.
>
> There is a value of n for which the number of apple trees equals the number of conifer trees. Find the value of n and show your method of calculating this.

Figure 3: The Modified Apples Task Used in the DELTA Project

Adapted from Mathematics Sample Tasks
OECD's 2009 PISA Assessment

Mathematics Unit 3: Apples

A farmer plants apple tree in a square pattern. In order to protect the apple trees against the wind he plants pine trees all around the orchard.

Here you see a diagram of this situation where you can see the pattern of the apple trees and the pine trees for any number (n) of the rows of apple trees:

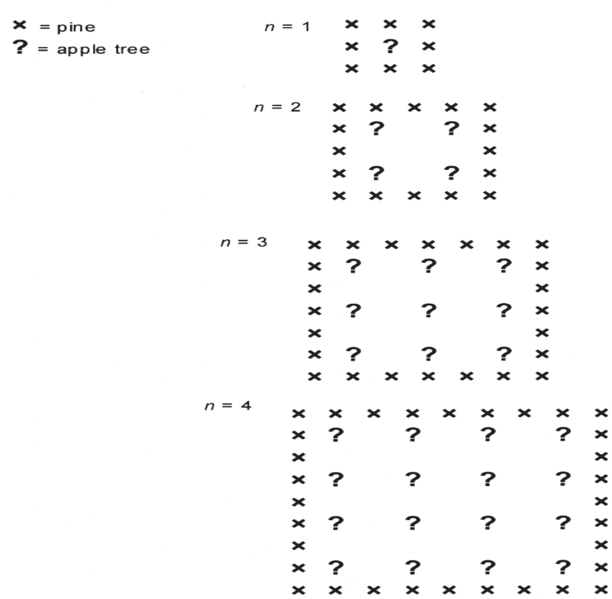


Figure 3: Continued

Adapted from Mathematics Sample Tasks
OECD's 2009 PISA Assessment

Question 3.1

Complete the table:

n	Number of apple trees	Number of pine trees
1	1	8
2	4	
3		
4		
5		

Question 3.2 [Note: different wording than in original PISA task]
Describe the pattern (words or symbols) so that you could find the number of apple trees for any stage in the pattern illustrated on the previous page:

Describe the pattern (words or symbols) so that you could find the number of pine trees for any stage in the pattern illustrated on the previous page:

For what value(s) of *n* will the number of apple trees equal the number of pine trees. Show your method of calculating this.

Question 3.3
Suppose the farmer wants to make a much larger orchard with many rows of trees. As the farmer makes the orchard bigger, which will increase more quickly: the number of apple trees or the number of pine trees? Explain how you found your answer.

The task modifications were intended to increase comprehension and accessibility for middle school students without affecting other key features of the task. In particular, the variation preserved the treatment of standard content in novel ways (e.g., juxtaposing a linear and quadratic pattern in the same problem context; including basic pattern finding with sophisticated reasoning about rates of change in the same item) and the cognitive complexity of the task (e.g., the use of multiple representations; calling for a range of processes, including analyzing, generalizing, and comparing). In fact, the modification actually may have increased the cognitive complexity of the task by making it more open-ended than was the original version.

The modified Apples task was used in several different ways in the DELTA project on multiple occasions. We summarize here the varied uses of this single task in this one professional development initiative because we think that they are illustrative of a range of possible uses of many PISA tasks in teacher preparation and professional development settings.

Teachers Solve the Problem

When the Apples task was first presented to the DELTA teachers, they were asked to solve the problem individually. They met in small groups to discuss and compare solution approaches, which provided an opportunity for the teachers to familiarize themselves with the mathematical concepts and skills associated with the problem. In this way, they were able to establish the relevance of the task to the mathematics that they teach, even though the task presentation likely differed from what they would find in the textbooks used in their classrooms.

Teachers Predict How Students Will Solve the Problem

After solving the problem, DELTA teachers were asked to anticipate what students at the grade level they taught would be likely to do if asked to solve the problem. After working individually, they met in small grade-alike groups to develop a list of shared anticipations for students at each grade level. The expectations were recorded on posters and displayed for general discussion.

The record of initial expectations came to play an important role in the learning of the DELTA project teachers. Subsequent examination of student work on the problem confirmed some of the teachers' expectations and challenged others. As we saw in a subsequent session, the surprises afforded especially important opportunities for teacher learning.

Teachers Examine the PISA Scoring Rubric

Teachers were provided with the PISA scoring guide, which is available for each of the publicly released tasks. They could see in the guide how PISA assigned points for various kinds of responses. Because the PISA task was modified when used in the DELTA project, only the portion of the rubric that pertained to the first and third questions was considered.

Teachers Collect Student Work on the Problem

As a homework assignment following the session in which they solved the Apples task, DELTA participants were asked to administer the task to at least one class of students, if feasible to do so. Collecting student work allows teachers to watch their own students solve the problem. It also provides a set of student responses that can be pooled across teachers to provide a more substantial sample of responses within and across grades. In DELTA, the teachers collected more than 900 responses from students in classrooms ranging from grades 5 through 12 and enrolled in a variety of mathematics courses (e.g., Algebra I, Algebra II, Pre-calculus). The diversity of student responses provided a rich resource for subsequent examination and analysis.

Teachers Examine the Student Work on the Problem

DELTA teachers were asked to examine the solutions produced by their students and then to meet with grade-level colleagues to examine all the student responses at their grade level. In their initial examination, they were asked to identify what the responses reveal about what students appear to understand and not to understand and what implications their observations might have for instruction. During the session, the grade-level group observations were recorded on poster paper and displayed in the room to facilitate a large group discussion that occurred later in the day.

Just as students can sometimes make discoveries while exploring problem situations that influence their sense of identity and agency, this type of activity on the part of teachers—a minimally guided exploration of student work—may yield profound insights. Nevertheless, some teachers may benefit from a more structured approach.

For a variety of reasons discussed by Silver and Suh (in press), including an emphasis on content coverage rather than on developing individual student understanding, many secondary school mathematics and science teachers tend to focus almost exclusively on correctness when examining student work. Crespo (2000) and Davis (1997) characterize this as an evaluative rather than interpretive orientation toward teaching. A teacher using an evaluative orientation tends to listen to students' ideas to judge them correct or incorrect and to diagnose and correct misunderstandings, similar to what Otero (2006) called a "get it or don't" conception of formative assessment.

This orientation was quite apparent among many DELTA teachers when they initially examined the student work on the Apples task. The poster displays and the grade-level and whole group discussions focused almost exclusively on right/wrong categories and an elaboration of students' errors and apparent misunderstandings, such as difficulties in setting up an equation to solve question 3.2c, missing 0 as a solution, rendering the repeated addition of 8 as n + 8 rather than as 8n, and confusing quadratic and exponential growth patterns. The professional development leaders had hoped for more attention to students' understandings, so they decided that it would be beneficial to return to the student work one more time in a future session, with an eye toward shifting teachers' attention to aspects of student performance other than correctness.

Teachers Analytically Examine the Student Work on the Problem

An UPDATE research team, including the authors of this paper, undertook an independent analysis of the student work on the modified Apples task, and paid particular attention to students' use of representations and strategies on questions 3.2 and 3.3. Two general observations emerged from our examination of the student work that we judged to have potential to engage the DELTA participants:

- When making claims and representing generalizations, students in upper grades and advanced classes tended to use mathematical symbolism and equations, whereas, in middle school and in lower level mathematics classes, students relied more often on verbal descriptions. Yet, even in upper level classes, students often used verbal descriptions to express a generalization.

- Some students at all grade levels used recursive strategies to solve subtasks 3.2a and 3.2b, with more using recursion for subtask 3.2b; students using recursion used only verbal descriptions rather than symbolic expressions to express their generalizations.

This analysis suggested a scheme that might be useful in drawing teachers' attention to more than right/wrong aspects of student work on the problem. Following our analysis of the student work, we created packets of student responses that contained specific examples to reflect the major strategies and representations evident in the full sample of student work: recursive description, recursive equation, explicit description, and explicit equation.

The response packets were used with the DELTA teachers in a subsequent professional development session, when the Apples task and student work once again became a focus of attention. Teachers were given the packets of student responses, and they were asked to sort the responses to questions 3.2a and 3.2b into the following groupings: Describe recursive pattern in words; (Try to) Express a recursive pattern using symbolic notation; Describe an explicit pattern using words; and Express an explicit pattern using symbolic notation.

Teachers Predict Frequency of Response Types

DELTA teachers also were asked to predict the percentage of students who would be likely to produce each type of response at the grade level that they teach (i.e., 15% of grade 8 students will use words to describe a recursive pattern in question 3.2a). Teachers worked individually at first, then in pairs, and, finally, in grade level groups to compare and refine their predictions.

Grade-level predictions were shared and discussed briefly in a whole-group session. In general, the predictions were that, as students progressed across the grades and through mathematics courses, they would become far more likely to express generalizations explicitly rather than recursively, and they would be far more likely to use symbolic expressions and equations rather than verbal descriptions. Once again, by having the teachers make such predictions, the professional developers hoped that the presentation of actual findings might include some surprises that could stimulate teacher learning.

Teachers Consider a Comprehensive Analysis of Student Responses

The UPDATE team presented its coding and analysis of the entire set of more than 900 student responses. For questions 3.2a and 3.2b, graphs were displayed to depict the frequency of student responses that expressed the generalization explicitly or recursively and that used verbal descriptions or symbolic expressions. The graphs vividly displayed the ways in which the student work aligned with or deviated from the teachers' predictions. For example, when looking across the grades, the graphs revealed not only a trend toward expressing generalizations explicitly and with symbolic expressions but also an unexpected persistence of both recursive reasoning and verbal descriptions.

The findings of the UPDATE analysis were discussed briefly in whole group, and then the participants met in grade-alike groups to discuss the findings and graphs as they pertained to their grade level. Teachers were encouraged to identify instructional issues raised by these findings—issues that pertained to their grade level and issues that might be pertinent across grade levels. Participants actively discussed and debated the findings and possible implications, moving fluidly between the graphs of general findings and the specific student responses that were available to them in the packets examined earlier in the day. Following discussion in grade-alike groups, the participants moved into cross-grade groups that mixed middle school and high school teachers. In these groups, participants discussed what the findings of this analysis suggested about what students were and were not learning from their mathematics instruction at each grade level and across grade levels as a means to increase curricular coherence, which was major point of emphasis in the DELTA project.

Reflection on the Use of the Apples Task

Although our presentation of the Apples task experience was necessarily brief and general, we think it embodies several points in regard to the use of PISA tasks as stimuli for STEM teacher professional learning. The first point is that the experience illustrates the diversity of ways that a PISA task might be used to stimulate teacher engagement and learning. The set of activity settings used in DELTA was extensive, and yet it represents only a sample of possibilities. Readers should be able both to generate other uses of the items for preservice and inservice teacher education settings and to think of variations on the specific activities and formats employed in DELTA. Moreover, it is important to think about the cumulative effects of a sequence of activities. In DELTA, the final professional learning activity appeared to have been critically important, but the experience of project participants in solving the tasks and predicting student solutions on prior occasions almost certainly played an important role in creating the learning opportunities that were manifested on that occasion.

A second point is that PISA tasks can be used as found in PISA or modified to fit the needs of a particular teacher education context. The original PISA Apples task was a challenging mathematical task that treated important mathematics concepts and skills and allowed for many legitimate uses as a stimulus for teacher professional learning. Yet, the modification that was made when the task moved from PISA to DELTA turned out to be important for two reasons. First, although it retained the mathematical character of the original PISA task, it made the task more accessible to middle school students who had not yet been taught to write and solve algebraic equations. Second, the modification opened the door to students' use of recursive reasoning to express the generalization. Our hunch is that recursion would have been far less likely to appear in the student work if the original PISA version of question 3.2 had been used, and the salience of recursion in the student work turned out to be a source of surprise for the teachers and, thus, an opportunity for their learning.

A closely related point is that the mixing of middle school and high school teachers in the participant group was useful for the teachers' work with the Apples task. The hybridity of the participant group made available a range of perspectives on how students might solve the task, generated a rich sample of student work, and supported participants' consideration of cross-grade curricular coherence issues. As Silver and Suh (in press) note, these factors played a role in the learning opportunities available to the DELTA teachers.

A final point is the importance of designing activities in ways that allow teachers, especially secondary school teachers, to move beyond a simple right/wrong evaluation of student work. In DELTA, participants made significant progress when they were presented with specific examples of student responses chosen in advance to represent particular strategies and representations and then directed to examine student responses using criteria that drew their attention toward matters of strategy and away from considerations of correctness.

Coda

If "STEM for All" is to succeed, we must ensure that all students in our schools and colleges become STEM literate. Teachers of mathematics and science are central to the success of current initiatives aimed at more and better STEM education. Teachers will need both excellent preparation and strong support to do their part. As we have argued in this paper, PISA can be a valuable source of support for teachers, teacher educators, and professional development specialists in pursuit of the STEM agenda in the United States. The time has come to unleash the learning power of PISA!

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