Teacher Viewpoints of Instructional Design Principles for Visuals in a Middle School Math Curriculum

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Objectives and Purpose

Teacher viewpoints on the curriculum they use are critical to the success of that curriculum (van Steenbrugge, Valcke, & Desoete, 2013) because teachers are the ones who implement the curriculum (Ball & Cohen, 1996; Lambdin & Preston, 1995; Manouchehri & Goodman, 1998; Remillard, 2005). In addition, based on their experience in the classroom, teacher viewpoints can provide valuable insight on the strengths and weaknesses of a curriculum (Even & Olsher, 2014; Oakley, 2012). Moreover, teacher viewpoints may enrich researchers' understanding of previous empirical findings and inform future investigations into improving learning materials.

In this research, we examine teacher viewpoints on the use of visuals in a commonly-used middle-school mathematics curriculum (*Connected Mathematics 2*, *CMP2*; cf., Banilower et al., 2012). We also investigate teachers' views of revisions that were made to those visuals as part of a randomized, controlled trial. In this paper, we first describe the curriculum revisions. We then report on teachers' viewpoints about visuals and the revisions that were made to visuals. We were especially interested in teachers' viewpoints on visuals for which there are conflicting theoretical perspectives.

Theoretical Framework Guiding Curriculum Revisions

CMP2 is rich with visuals, such as pictures, diagrams, and other spatial representations, which are used in coordination with the text of the lessons and activities (Authors, 2012). However, the ways visuals are used in the lessons and activities do not always make effective use of students' cognitive resources. Instructional design principles that specify how visuals should be integrated with text have been developed, with the broad aim being to optimize comprehension and learning (cf. Mayer, 2009; Sweller, Ayres, & Kalyuga, 2011). Our research team applied these design principles to revise the visuals in *CMP2*.

Four instructional design principles guided our revisions: multimedia, signaling, contiguity, and coherence. According to the *multimedia principle*, learning is greater when texts are accompanied by relevant visuals (Mayer, 2009) because students develop a verbal mental representation from the text and a visual mental representation from the visuals. Students are more likely to make connections among different ideas when the information is represented in two distinct mental representations (Mayer, 1999; Mayer & Gallini, 1990). Based on the multimedia principle, math-relevant visuals were added whenever appropriate to the revised curriculum (see Figure A1 in the appendix for an example).

The signaling and contiguity principles guided revisions to the existing visuals in *CMP2*. According to the *signaling principle*, learning is improved by cues, such as color coding, to important information (Mayer, 2009). Cues may improve learning both by directing a student's attention and by connecting corresponding information across different representations (e.g., text and visuals: Kalyuga, Chandler & Sweller, 1999; de Koning, Tabbers, Rikers, & Paas, 2009).

The *contiguity principle* states that information should be arranged such that relevant information in different representations are in close proximity so students may focus their cognitive resources on understanding the ideas presented in the lesson (e.g., Ginns, 2006; see Figures A2, A3, and A4).

The *coherence principle* states that learning is improved when interesting, but irrelevant information is removed (Mayer, 2009). This type of information has been found to distract learners and diminish comprehension in a phenomenon referred to as the *seductive details effect* (e.g., Lehman, Schraw, McCrudden, & Hartley, 2007). Following this principle, visuals that were math-irrelevant and not critical to understanding the problem context were removed. This included visuals that were decorative (i.e., for aesthetic purposes only) or representational, in that they were related to the context of the lesson or story problem (cf. Elia & Philippou, 2004; see Figures A5 and A6)

Many of the decisions regarding the application of instructional design principles were simple, such as adding color coding or ensuring that relevant text and visuals were in close spatial proximity. This is because the theoretical background and empirical evidence regarding those decisions were clear. In contrast, removing representational visuals was supported by the coherence principle, but not the multimedia principle. In other words, it is was uncertain whether representational visuals would distract from the mathematics, as articulated in the coherence principle or whether they would provide visual support for understanding the context of the lesson, as articulated in the multimedia principle (cf. Mayer, 2009). The issue of visual support may be especially true for English Language Learners for whom representational visuals have been shown to help with some aspects of reading comprehension (Pike, Barnes, & Barron, 2010). For these reasons, representational visuals that provided critical support for understanding the context of a lesson were not removed (see Figure A7). In addition, the use of visuals for aesthetic purposes only could increase interest, although this has not been shown to benefit learning (Magner, Schwonke, Aleven, Popescu, & Renkl, 2013; Mayer, 2014). Giving these complexities, the viewpoints of teachers regarding math-irrelevant visuals could be very informative.

Details of the Curriculum Changes

Teacher viewpoints on decorative and representational visuals may be especially informative given the predominance of these visuals. As can be see in Table 1, many visuals from the original CMP2 were math-irrelevant (i.e., representational or decorative) or were math-relevant (i.e., graph, table, diagram) with math-irrelevant features. Thus, majority of our revisions dealt with removing math-irrelevant visuals (see Table 2). In general, the math-relevant visuals were already well designed; so we improved integration when possible.

Table 1

Categorization of visuals in original 7th grade *CMP2* curriculum

Category	*N*	% of visuals
Math-irrelevant	201	47%
Math-relevant with math-irrelevant features	72	17%
Diagram	46	11%
Table	45	10%
Graph	36	8%
Other	32	7%
Total	*432*	*100%*

Table 2

Revisions made to visual representations

Revision Category	Specific Change Type	*N*	% of Revisions
Whole Visual	Remove decorative or representational illustration	274	69%
	Added new mathematically-relevant visual	13	3%
Text – Visual Integration	Move visual or text for spatial contiguity	19	5%
	Added text reference or clarify for better integration w/ visual	42	11%
Modifications within an Existing Visual	Add or improve labels in visual	15	4%
	Spatial re-organization within visual	17	4%
	Other (e.g., color code, other visual improvements)	35	9%

Note. The total number of revisions was 415 across 397 instances (i.e., some visuals received more than one revision); thus the percentage of instances with a specific change type sum to over 100%.

To examine teachers' views about visuals in mathematics curricula, we asked teachers who participated in the RCT to complete a survey. From the survey responses, we sought to answer three research questions:

1. Did teachers in the control group have favorable viewpoints toward the visuals used in the original CMP2 books?
2. Did teachers in the treatment group have favorable viewpoints toward the changes in visuals from the original to the revised books?

3. How did viewpoints differ between teachers in the control and revised groups? For this question, we were particularly interested in examining issues related to math-irrelevant visuals.

Methods

Data Sources

In the RCT, schools were nationally sampled and randomly assigned to the treatment (32 schools, 59 teachers) or control (31 schools, 55 teachers) condition. Treatment teachers received professional development in the form of presentations and brief readings on the instructional design principles. Of the treatment teachers, 22 teachers (37%) responded to part or all of the survey items; 21 control teachers (38%) did so.

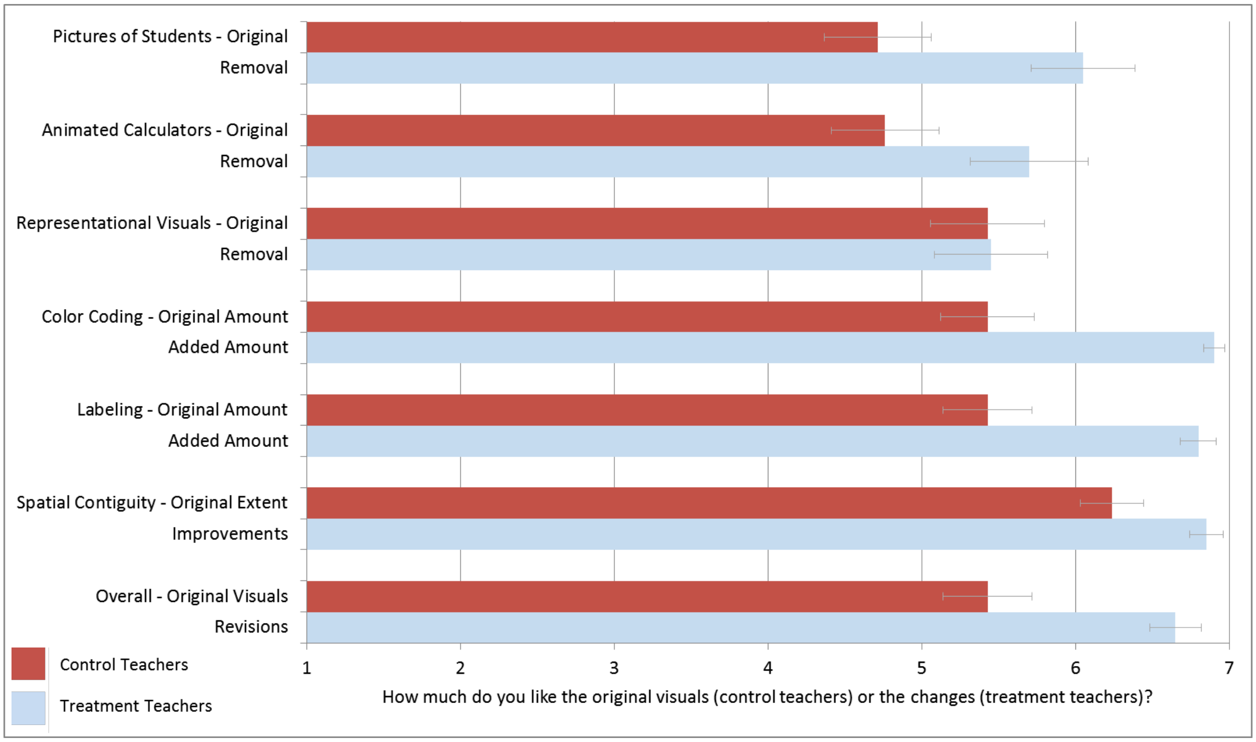
The first part of the survey asked teachers to indicate how much they liked decorative pictures of sample students, representational images associated with a problem's context, decorative images of animated calculators, the amount of color coding, the amount of labeling in visuals, and the spatial location of visuals relative to corresponding materials as well as an overall ratings of the book's visuals. Treatment teachers responded to the same topics, but their questions were phrased in terms of the modification made to each of these categories (e.g., how much do you like the removal of representational visuals) with the final item asking the treatment teacher's opinions of the overall changes. For each of these items, teachers were given either visual examples or extended verbal descriptions of examples.

The second part of the survey asked about teachers' viewpoints of the visuals on learning. The topics considered here are presented along with the data in Figure 2. Finally, teachers were asked an open-ended question about whether they thought representational visuals helped were beneficial.

Results

Our first research question was whether teachers in the control group had favorable views toward the visuals used in the original CMP2 books. As seen in Figure 1, on the whole, they did. They gave generally favorable ratings to the use of labeling, color coding, and spatial contiguity in the visuals. Control teachers also generally liked the inclusion of math-irrelevant visuals, whether decorative or representational.

Figure 1. Control and treatment teachers' viewpoints of different types and features of visual representations. Each group responded on a 1 (Strongly Dislike) – 7 (Strongly Like) Likert scale. Control teachers' responses indicate their evaluation of that aspect of the visuals in the original books. Treatment teachers' responses indicate their evaluation of the change to type or feature of visuals in the revised book.



Our second research question was whether teachers in the treatment group had favorable views toward the changes in visuals from the original to the revised books. Treatment teachers generally liked the revisions, especially the increased use of color coding and labeling (see Figure 1). Treatment teachers appeared to generally approve of the removal of decorative visuals. They were less enthusiastic, but still generally supportive, of the removal of representational visuals. In addition, by comparing the responses of the control and treatment teachers to each of these categories of items we see that the treatment teachers liked the revisions at least as much as the control teachers liked the originals.

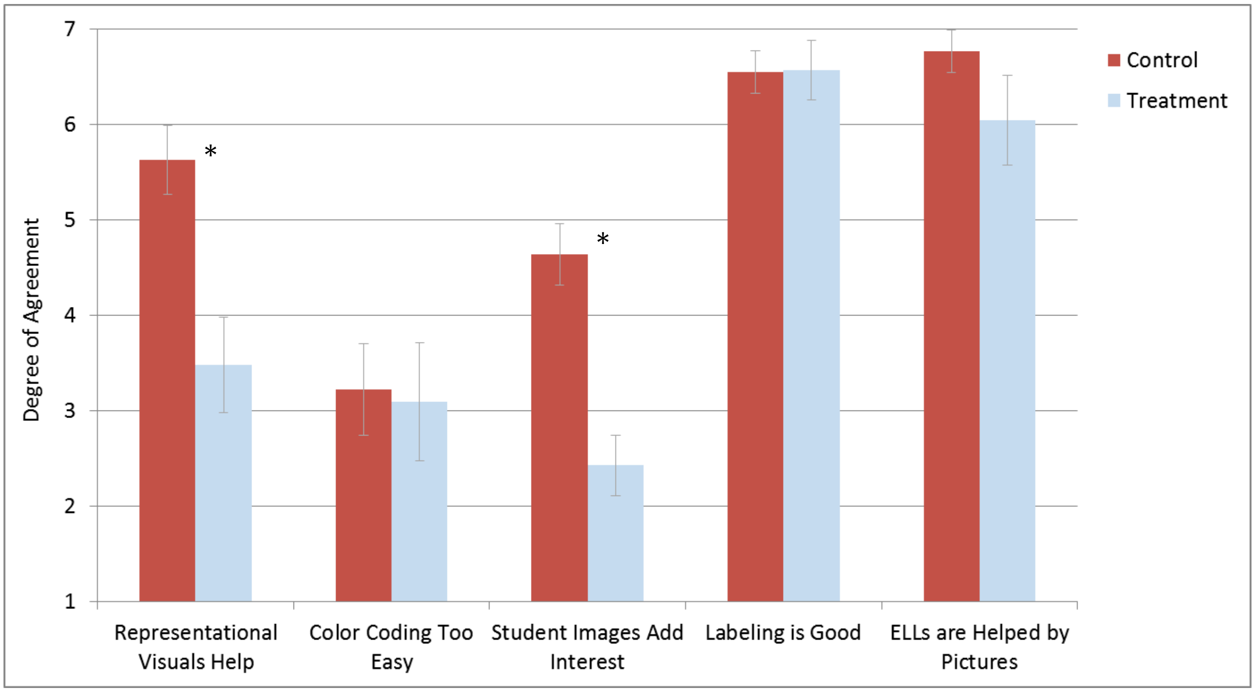
Finally, we compared the responses of treatment and control teachers on statements related to instructional design principles for visuals, that is, their belief about the effects of the visuals on learning. As seen in Figure 3, both sets of teachers strongly believed in the benefits of labeling, generally disagreed that color coding made the lessons too easy, and they also believed that ELL students are helped by pictures.

However, there were also some differences in opinions among the two groups. Treatment teachers viewed math-irrelevant visuals less favorably than did control teachers, $t(41) = 3.54$, $p =$

.001 (representational visuals) and $t(41) = 4.88$, $p < .001$ (student images), respectively. Thus, teachers' use of the revised CMP2 curriculum and the associated PD appears to have influenced teachers' views about math-irrelevant visuals. In fact, these teachers viewpoints were negative towards these claims about representational and decorative visuals.

Figure 2

Control and treatment teachers' responses about instructional design principles for visuals (on 1 [Strongly Disagree] – 7 [Strongly Agree] Likert of how much they agreed with the statements)



Note. * $p <= .001$

We also examined teachers' viewpoints on representational visuals using an open-ended question: Do you think pictures about the context of the lesson or story problem help students? Responses were coded into three categories, depending on whether the response considered pictures as helpful: yes, maybe/depends, and no; examples of the responses are in Table 4.

Table 4

Responses to "Do you think pictures about the context of a lesson or story problem help students?"

Control Teachers

Category (Number of Responses in Category)	Example Reponses
Yes (13)	Yes, I think it makes the lesson more engaging and less intimidating to students.

	Yes because it ties them to a real problem and it helps them make the connection to the problem.
Maybe/It Depends (3)	It may provide interest, or distract some kids.
No (2)	Not particularly. I think that sometimes pictures are just a distractor, and can discourage students because the problem looks longer.

Treatment Teachers

Category (Number of Responses in Category)	Example Reponses
Yes (4)	I think they do because they grab the student's attention and they are very helpful for English Language Learners.
Maybe/It Depends (9)	It my help them make a connection, but often it is more distracting that anything else. Often the students cannot get over what the kid in the picture is wearing, etc. I am not opposed to pictures that support or enhance the meaning of the problem. If the picture is there just to spice it up, I'd prefer it be left out. I think they may increase interest for some students, but I do not think they impact the actual learning of mathematics. I think students' ability to learn mathematics is connected to their knowledge framework far more than it is to their viewing of a related picture.
No (7)	No, I have not found that pictures about the context of the lesson have any value except to distract from the actual question. I also do not believe they make the content more interesting. Student engagement is more important that a text book with pretty pictures. I think they are distracting. Students begin

	talking about the picture instead of focusing on the math.

These responses provide further support for the claim that participation in the RCT affected teachers' viewpoints on representational visuals, as the distribution of teacher responses across categories differed for control and treatment teachers, $\chi^2(2, N = 38) = 10.47, p < .01$). Among the treatment teachers, 45% expressed both pros and cons of visuals in their responses (compared to only 17% of control teachers), indicating a greater awareness of the complexities involved in the use of representational visuals. In contrast, 72% of the control teachers viewed representational visuals as uniformly helpful (compared to only 20% of treatment teachers).

Significance

The purpose of this study was to examine teacher viewpoints on the visuals in the original CMP2 curriculum and visuals in CMP2 curriculum that were revised based on instructional design principles. Generally, teacher viewpoints were in line with theories and empirical evidence for our instructional design principles (cf. Mayer, 2009). Control teachers recognized the benefits of the existing color coding, labeling, and spatial contiguity, and the treatment teachers were able to recognize that all of these items had improved in the revised books. In this way, our findings support the use of these techniques in mathematics curriculum—teachers likely view these techniques positively because teachers have witnessed benefits for student learning.

The findings also highlight the complexities with one particular type of modification—removal of visuals that were math-irrelevant, but were representations of the context of the lesson or story problem. Viewpoints on representational visuals were mixed, although control teachers generally indicated more support for these images than did treatment teachers. Many teachers, especially those in the treatment condition, indicated that representational visuals could be either beneficial or distracting depending on the situation and the student. This may explain why previous work had indicated that the inclusion of representational visuals has been found to have no influence on mathematics performance (Cooper et al., 2013; Dewolf, van Dooren, Ev Cimen, & Verschaffel, 2014)— conflicting effects of representational visuals could lead to null effects overall. Future work in the area of representational visuals and mathematics could investigate this possibility by identifying populations of students who may be differentially affected by representational visuals (e.g., English Language Learners and special education students) as well as contexts in which representational visuals may be particularly informative (e.g., challenging or unfamiliar contexts). Such work examining teacher viewpoints could inform curriculum design so that visuals are optimal for student learning.

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Appendix

Figure A1. Example of revisions based on the multimedia principle.

Original = Text Only

Revised = Added Labelled Diagram

The **base** of a rectangular prism is the face on the bottom (the face that rests on the table or floor). The length and width of a prism are the length and width of its rectangular base. The height is the distance from the base of the prism to its top.

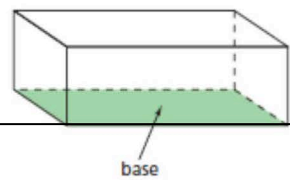


Figure A2. Example of revision based on the signaling principle (color coding)

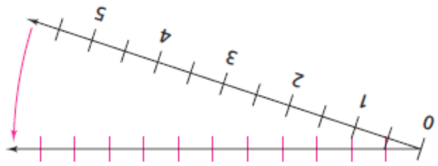
Original

Take the number line and fold it around the zero point. Make marks on the left side of zero to match the marks on the right side.

Label the new marks with numbers that have negative signs (-). These numbers (to the left of 0) are **negative numbers.**

Revised

Take the number line and fold it around the zero point. Make marks on the left side of zero to match the marks on the right side.



Label the new marks with numbers that have negative signs (⁻). These numbers (to the left of 0) are **negative numbers.**

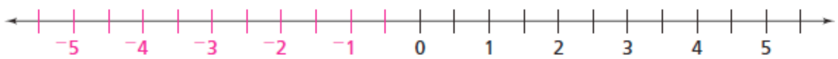


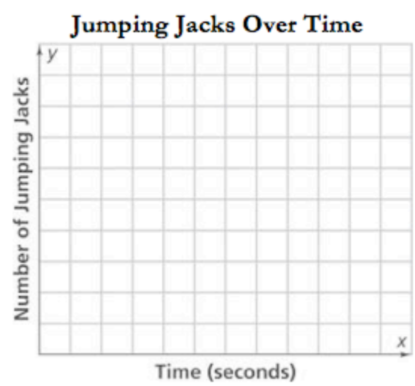
Figure A3. Example of revision based on the contiguity principle (labeling).

Original

If time is a variable, you usually put it on the *x*-axis. This helps you see the "story" that occurs over time as you read the graph from left to right.

In Problem 1.1, the number of jumping jacks depends on time. So, put number of jumping jacks (the dependent variable) on the *y*-axis and time (the independent variable) on the *x*-axis.

Label your graph so that someone else can see what it represents. You can label the *x*-axis as "Time (seconds)" and the *y*-axis as "Number of Jumping Jacks." You can use these labels to help you choose a title for your graph. You might title this graph, "Jumping Jacks Over Time."



Revised

If time is a variable, you usually put it on the *x*-axis. This helps you see the "story" that occurs over time as you read the graph from left to right.

In Problem 1.1, the number of jumping jacks depends on time. So, put number of jumping jacks (the dependent variable) on the *y*-axis and time (the independent variable) on the *x*-axis, as shown in the graph to the right.

Label your graph so that someone else can see what it represents. You can label the *x*-axis as "Time (seconds)" and the *y*-axis as "Number of Jumping Jacks." You can use these labels to help you choose a title for your graph. You might title this graph, "Jumping Jacks Over Time."

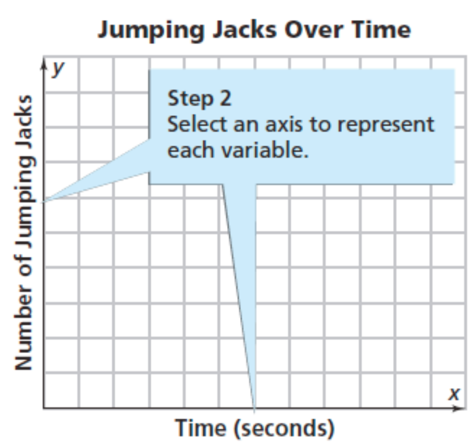


Figure A4. Example of revision based on the contiguity principle (close physical proximity).

Original

(The table and the problems based on the table were on separate pages.)

Revised

Selected Champion Trees

Tree Type	Circumference (ft)	Height (ft)	Spread/Diameter (ft)
Giant Sequoia (Calif.)	83.2	275	107
Coast Redwood (Calif.)	79.2	321	80
Swamp Chestnut Oak (Tenn.)	23.0	105	216
Florida Crossopetalum (Fla.)	0.4	11	3
White Oak (Md.)	31.8	96	119

SOURCE: *Washington Post*

Problem 1.3 Writing Comparison Statements

A. Use the table above.

1. How many coast redwood spreads does it take to equal the spread of the white oak?
2. Kenning says that the spread of the white oak is greater than that of the coast redwood by a ratio of about 3 to 2. Is he correct? Explain.
3. Mary says the difference between the heights of the coast redwood and the giant sequoia is 46 feet. Is she correct? Explain.
4. How many giant sequoia spreads does it take to equal the spread of the swamp chestnut oak?
5. Jaime says the spread of the giant sequoia is less than 50% of the spread of the swamp chestnut oak. Is he correct?
6. Len says the circumference of the swamp chestnut oak is about three fourths the circumference of the white oak. Is he correct?

Figure A5. Example of revisions based on the coherence principle (removal of decorative visuals).

Original

Is the price of a box of cereal directly related to its volume?
Collect some data to help you answer this question.

a. Record the dimensions and prices of two or three different-sized boxes of the same cereal brand.
b. Calculate the volume of each box.
c. Calculate the cost per unit of volume for each box. Compare the results for the different boxes.
d. Write a short report summarizing what you learned about the relationship between box size and cereal price.

Revised

Is the price of a box of cereal directly related to its volume?
Collect some data to help you answer this question.

a. Record the dimensions and prices of two or three different-sized boxes of the same cereal brand.
b. Calculate the volume of each box.
c. Calculate the cost per unit of volume for each box. Compare the results for the different boxes.
d. Write a short report summarizing what you learned about the relationship between box size and cereal price.

Figure A6. Example of revision based on the coherence principle (removal of a representational visual).

Original

30. The greatest one-day temperature change in world records occurred at Browning, Montana (bordering Glacier National Park), from January 23–24 in 1916. The temperature fell from 44°F to $^{-}56$°F in less than 24 hours.

a. What was the temperature change that day?

b. Write a number sentence to represent the temperature change.

Revised

30. The greatest one-day temperature change in world records occurred at Browning, Montana (bordering Glacier National Park), from January 23–24 in 1916. The temperature fell from 44°F to $^{-}56$°F in less than 24 hours.

a. What was the temperature change that day?

b. Write a number sentence to represent the temperature change.

Figure A7. Example of representational visual included in the revised curriculum to assist with vocabulary from the lesson context.

Original and Revised

Here is a situation that uses decimals, but does not involve money. Use what you know about measurement and place value to help you think about the problems.

Every year, students at Memorial High School volunteer to clean local highway roadsides. Each club or team at the school is assigned a section of highway to clean.

One member of a club measures out each member's part of the section of highway using a trundle wheel. A trundle wheel, shown in the picture to the right, can measure distances in thousandths of a mile.