Conceptual Framework for Analyzing and Designing Illustrations in Science Assessment: Development and Use in the Testing of Linguistically and Culturally Diverse Populations

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Abstract

We present a conceptual framework for designing and analyzing illustrations used in science assessment. This conceptual framework is intended to help test developers to systematically create and examine illustrations used in science test items. Unlike previous approaches to examining illustrations, which rely on the use of vague or polysemic terms to describe illustrations (e.g., *graph, diagram*), our conceptual framework uses illustration dichotomous variables (IDVs) as a basis for describing the presence or absence of different visual features. These IDVs are organized according to five main categories: (1) Representation of objects and background, (2) Metaphorical visual language, (3) Text in illustration, (4) Representation of variables, constants, and functions, and (5) Illustration-text interaction. We discuss two studies, currently in progress, in which we have applied our conceptual framework. In a first study, the framework has allowed us to specify the desired features of vignette illustrations—illustrations added to the text of test items originally created without illustrations with the intent to provide a visual support for English language learners who are given science tests in English. In a second study, we are comparing the characteristics of science tests used in China and in the U.S. Preliminary results show that our conceptual framework allows test developers to systematically design illustrations. They also show that our conceptual framework allows identification of important cultural differences in the characteristics of illustrations used in science tests. We discuss how this conceptual framework can contribute to enhanced test development practices.

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This paper addresses a neglected aspect in both research and practice concerning the process of design in science assessment—illustrations. We address the fact that assessment frameworks and other normative documents from key assessment programs such as NAEP (the National Assessment of Educational Progress; WestEd & Council of Chief State School Officers, 2007) provide scant information for designing and evaluating illustrations in large-scale assessment. In the absence of a framework on illustrations, test developers are unlikely to be able to systematically design and use illustrations in tests.

We propose a conceptual framework for analyzing and designing illustrations. We have created this conceptual framework based on our experience developing illustrations for science items originally created without illustration and after examining over 600 illustrated science and mathematics items from national and state assessment systems in the U.S. and different regional assessment systems in China. We also created the conceptual framework based on current knowledge from the fields of cognitive science (Mayer, & Sims, 1994; Paivio 1971, 2006), literacy (Cope & Kalantzis, 2000; Kress & van Leeuwen, 1996), and linguistics and sociocultural theory (Vygotsky, 1978; Wertsch, 1985).

To show empirical evidence on the effectiveness of our conceptual framework as an analytical tool for test developers, we discuss how we are using our conceptual framework in two projects, currently in progress.

Conceptual Framework

While multiple forms of illustration have been proposed as resources that can help test takers to demonstrate their knowledge (Fichtner, Peitzman, & Sasser, 1994; O' Malley & Valdez-Pierce, 1996; Shanahan, 2006), the sole use of illustrations is not a guarantee of better testing practices. Not all illustrations improve understanding; adding interesting but irrelevant visual stimuli to text can hamper, rather than facilitate, the process of making sense of information (Harp & Mayer, 1997, 1998; Mayer, Heiser & Lonn, 2001). To be effective, illustrations should mirror or replace text without being distracting (Filippatou & Pumfrey, 1996).

While researchers have made efforts to study the effectiveness of line drawings, diagrams, graphs, tables, and other forms of illustration in textbooks, available literature (e.g., Dimopoulos, Koulaidis, & Sklaveniti, 2003; Evans, Watson, & Willows, 1987; Fleming, 1966; Goldsmith, 1987; Hunter, Crismore, & Peason, 1987; Kosslyn, 2006; Levie & Lentz, 1982; Levin, Anglin, & Carney, 1987; Weidenmann, 1994; Winn, 1987) does not provide detailed information on the conceptual foundations and the methods used to examine and create illustrations.

This lack of conceptual formality is aggravated by the fact that terms such as *graph, diagram,* or *schematic,* commonly used in research on illustrations in science (e.g., Ametller & Pinto, 2002;Carrick, 1978; Colin, Chauvet, & Viennot, 2002; Pauwels, 2008), are frequently used as interchangeable, can be interpreted in multiple ways, and fail to capture important differences between cases within a given broad category (e.g., two illustrations labeled, *graphs* may differ tremendously in form, style, and complexity and may contain elements typically associated with other forms of illustration).

To overcome these limitations, we focus on illustration dichotomous variables (IDVs) as units of analysis. We define IDVs as features whose combined presence or absence determine the characteristics of a given illustration. Also, we define *illustration* as a mainly non-textual device whose characteristics can be described according to sets of IDVs. *Mainly non-textual* addresses the fact that illustrations commonly used in science printed materials contain text (e.g., in labels, legends, or captions.

Table 1.
Illustration dimensions (bold letters), categories (underlines), and variables (italics) identified in the conceptual framework for designing and examining science test item illustrations.

1. Representation of objects and background
- 1.1. Image concreteness: *1. photograph, 2. realistic line drawing, 3. scheme, 4. silhouette, 5. cartoon, 6. logo/icon/emblem, 7. metonymy, 8. symbol, 9. reference, 10. entity*
- 1.2. Background: *1. with background, 2. without background*
- 1.3. Zooming: *1. zoom-in, 2. zoom-out, 3. zero zooming naked eye*
- 1.4. View: *1. external, 2. cross-section, 3. segmentation, 4. transparency, 5. permanence, 6. virtual window, 7. X-rays, 8. other*
- 1.5. Projection: *1. 3D, 2. 2D*
- 1.6. Relative position of objects: *1. preserved, 2. altered*
- 1.7. Relative scale of objects: *1. proportionate, 2. disproportionate*
- 1.8. Color: *1.black & white, 2. multicolor, 3. gray scale*
- 1.9. Constituents: *1. subject (no background), 2. subject (with background), 3. subject performing an action (no background), 4. subject performing an action (with background), 5. subject performing an action that affects an object (no background), 6. subject performing an action that affects an object (with background)*

2. Metaphorical visual language
- 2.1. Space, time, and motion: *1. space* (e.g., location), *2. time* (e.g., sequence), *3. dynamics* (e.g., flow)
- 2.2. Matter and energy: *1. states of matter* (e.g., gas), *2. temperature* (e.g., coldness), *3. light and electricity* (e.g., brightness), *4. sound* (e.g., noise)
- 2.3. Human state: *1. senses* (e.g., seeing), *2. speech and cognition* (e.g., utterance), *3. physical condition* (e.g., freezing), *4. emotion* (e.g., crying)

3. Text in illustration
- 3.1. Text unit: *1. non-scientific/mathematical symbol, 2. scientific/mathematical symbol, 3. abbreviation, 4. Roman numeral, 5. Arabic numeral, 6. letter, 7. word, 8. phrase, 9. sentence, 10. paragraph*
- 3.2. Text function: *1. label, 2. code/legend/explanation, 3. title, 4. caption/heading, 5.elaboration, 6. comment/note, 7. instructions*

4. Representation of variables, constants, and functions
- 4.1. Variables and constants: *1. case, 2. stage, 3. level, 4. line, 5. value, 6. scale, 7. unit*
- 4.2. Function: *1. graph, 2. table, 3. nodes/arcs, 4. formula/equation, 5. symbol*
- 4.3. Structure: *1. sequence, 2. tree, 3. cycle, 4. network*

5. Illustration-text interaction
- 5.1. Location of illustration: *1. above stem/prompt, 2. between stem/prompt and options/response format, 3. embedded in stem/prompt, 4. embedded in options/response format, 5. at the left of the prompt, 6. at the right of the prompt*
- 5.2. Reference to illustration: *1. explicit, 2. not stated*
- 5.3. Stated actions to perform with the illustration: *1. observe or examine, 2. draw, mark or write on illustration provided, 3. generate an illustration, 4. no action stated*
- 5.4. Commonality: *1. part of a stand-alone item, 2. same illustration for several items, 3. illustration for one item with a series of related items*

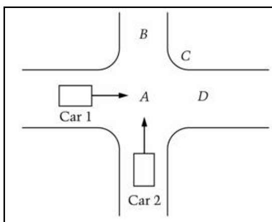
In our conceptual framework, IDVs can be grouped in five dimensions: 1) Representation of objects and background, (2) Metaphorical visual language, (3) Text in illustration, (4) Representation of variables, constants, and functions, and 5) Illustration-text interaction (Table 1).

Figure 1 shows an illustrated science item and Table 2 shows the analysis of the illustration of that item for the category, *1.1. Representation of Objects and Background*. For analytical purposes, the categories of illustration variables can be treated as vectors. Thus, since the concreteness of the illustration of the item shown in Figure 1 is regarded as schematic (see third variable in Category 1.1, Table 1), the coding for the category, *1.1. Image Concreteness* for that illustration is described by the vector:

C1.1=[0 0 1 0 0 0 0 0 0 0].

The variables within a given category are not necessarily mutually exclusive. For example, the illustration of the item shown in Figure 1 contains letters used to designate location (*A*, *B*, *C*, *D*) and phrases (*Car1, Car 2*). ("1" and "2" are not coded as Arabic numerals because they do not stand alone in the illustration, do not denote quantity, and are part of phrases). Thus, the coding for the category, *3.1 Text Unit* for that illustration is described by the vector:

C3.1=[0 0 0 0 0 1 0 1 0 0].



Two identical cars travel at 45 miles per hour toward the center of the intersection (point A, as shown above) with equal force. The cars collide at the intersection. If after they collide the cars stick to each other and move together, they will come to rest closest to

1. point A
2. point B
3. point C
4. point D

Figure 1. An illustrated science item. Source: National Assessment of Educational Progress. (2005). *NAEP 2005 Science Assessment Public Released Items for Grade 8.* Retrieved September 18, 2009, from http://nces.ed.gov/nationsreportcard/itmrlsx/search.aspx?subject=science

Table 2. *Analysis of the representation of objects and background for the illustration of the item shown in Figure 1.*

1.1. Image concreteness: Schematic—the representation eliminates unnecessary elements (e.g., signal lights, other cars, details of roads)
1.2. Background: With background—the cars are shown with reference to the intersection
1.3. Zooming: Zero zooming—the cars and intersection are shown as seen with the naked eye
1.4. View: External—the illustration does not show the inside of any component
1.5. Projection: 2-D—only the length and width (not depth) of the objects are shown
1.6. Relative position of objects: preserved—the relative position of the cars with each other is shown as described in the text of the item
1.7. Relative scale of objects: Disproportionate—the cars appear to be bigger than they really are, in relation to other components in the illustration, such as the road
1.8. Color: Black and white
1.9. Constituents: Subject performing an action (with background)—two cars are running toward the center of an intersection in the street

Evidence on the Utility of the Conceptual Framework

Evidence on the effectiveness of the conceptual framework as an assessment development tool comes from two investigations, currently in progress, in which we have applied it. The first study investigates how illustrations can be used to make the content of science items more accessible to English language learners (ELLs) tested in English (Solano-Flores, 2010a, b; 2011). The second study examines the characteristics of illustrations in items used by state, national-U.S., national-China, and international (TIMSS) science assessment programs (Wang & Solano-Flores, 2010a; 2011).

Vignette illustrations in the testing of ELL students

This investigation addresses the need for effective forms of testing accommodations for English language learners. We are examining whether and how vignette illustrations can improve ELL students' access to the content of science items without giving away the responses or altering the constructs measured. *Vignette illustration* is the term we are using to refer to an illustration added to a test item originally written without illustration without altering the text of the item. While some literature on ELL testing encourages test developers to use images as visual supports, illustrations have not been proposed formally as a form of testing accommodation. Indeed, illustrations are not listed among the dozens of testing accommodations used by state assessment systems (see (Rivera, Collum, Willner, & Sia, 2006).

As part of the investigation, we have created a procedure for developing testing illustrations based on the analysis of the linguistic challenges that science items are likely to pose to ELLs due to cultural and linguistic differences. The details of the procedure are explained elsewhere (Solano-Flores, 2011). We have used the conceptual framework to formalize the set of characteristics that all the illustrations generated in the project should have in order to ensure standardization and consistency in design. For example, we decided that, among other characteristics, our illustrations should: (1) represent only one or two of the constituents (words, phrases, idiomatic expressions) identified in the text of the items as likely to pose a challenge to ELL students; (2) consist of line drawings (not photographs); (3) offer simplified, realistic (not iconic or cartoony) representations of the identified constituents; (4) offer representations of concrete objects and situations that could be seen by the examinee from direct experience (as opposed to abstract representations of phenomena not visible with the naked eye); (5) not contain any text (e.g., labels or letters); (6) not represent any sequence of actions or stages; (7) minimize the use of metaphorical visual language (e.g., arrows, dotted lines); (8) be mainly black and white, and (9) appear at the right of the items. Also, we specified certain design features not considered in the framework, such as the absence of margins, and the specific dimensions (1.5 inches long by 1.5 inches wide) of the vignette illustrations. An example from an investigation that examines ELL students' problem solving strategies when they take science illustrated and non-illustrated (Prosser, 2010) is shown in Figure 2.

Evidence on the effectiveness of vignette illustrations based on student performance is currently being collected. As part of our analyses, we are examining the interaction of illustration, the content of the item, and characteristics of the students.

Maria wanted to measure the amount of time it took for a ball to roll down a ramp. She had never used a stopwatch before. Kevin gave her the following directions, but they were in the wrong order.

Step 1: Hold the stopwatch in one hand.
Step 2: Press the button once to start the clock.
Step 3: Press the button twice to clear any old times.
Step 4: Press the button to stop the clock.
Step 5: Let the watch run until it is time to stop it.
Step 6: Record the amount of time.

How should she arrange Kevin's steps so they are in the correct order?

A. 1, 5, 2, 3, 4, 6
B. 1, 2, 3, 5, 4, 6
C. 1, 3, 2, 4, 5, 6
D. 1, 3, 2, 5, 4, 6

Figure 2. An example of a vignette-illustrated science item. The illustration was added to the text of the item. Sources: Arizona Department of Education (2009). *Arizona Instrument to Measure Standards (AIMS) 2009 Science Sample Test for Grade 8.* Retrieved October 28, 2009, from http://www.ade.state.az.us/standards/aims/sampletests/Gr8-AIMSsampletestscience.pdf

Characteristics of illustrations used in different assessment programs

This investigation addresses the possibility that culture influences the ways in which illustration conventions are used and interpreted (Boling, Eccarius, Smith, & Frick, 2004; Boling, Smith, Frick, & Eccarius, 2007; Knight, Gunawardena, & Aydin, 2009; Schiffman, 1996; Wang & Solano-Flores, 2010b). Our sample of items was drawn from a corpus of over 800 released multiple-choice and constructed-response science items for Grade 8/9 (Note 1) from the National Assessment of Educational Progress (NAEP), Years 2000, 2005, and 2009, the District of Columbia Comprehensive Assessment System (DCCAS), Year 2009, the New York State Assessment (NYSA), Year 2009, the California Standards Tests (CSTs), Years 2006, 2007, and 2008, the Texas Assessment of Knowledge and Skills (TAKS), Year 2009, and China's Middle School Exit Examination (CMSEE; Beijing, Chongqing, Tianjin, Shanghai, Nanjing, Changchun, and Jinan), Years 2009 and 2010. Most of the assessments were generated in most populous cities or regions in the U.S. and China. About 35% of the test items (276) have some kind of illustration.

Using a multistage cluster sampling method (see Freedman, Pisani, & Purves, 2007), we have randomly selected items from this corpus of items to attain a balanced design with equal sizes from each of four science content areas—Physics, Chemistry, Earth Science, and Life Sciences—for both the U.S. and China.

Results from preliminary analyses suggest that the coding system developed based on our conceptual framework is sensitive to cultural differences in the complexities of different assessment systems. Figure 3 provides an example. The histograms show the frequencies of numbers of different features (IDVs) observed (coded 1) in items generated in the U.S. and items generated in China.

As the shape of the distributions shows, illustrations from China tend to have a wider range of features than illustrations from the U.S. This finding indicates that illustrations from China tend to have more and more varied characteristics than their U.S. counterparts.

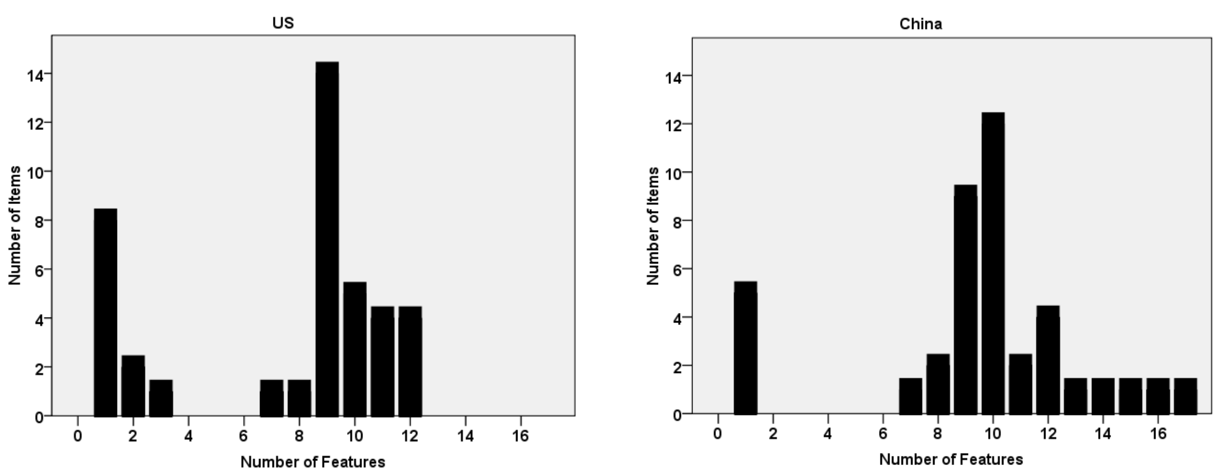


Figure 3. Different number of features (IDVs) observed (coded 1) in science items generated in assessment systems in the U.S. and in China: Representation of objects and background.

Final Comments

While illustrations are widely used in large-scale assessment, no procedures are available for their systematic design and use. In this paper, we have presented a conceptual framework for examining illustrations used in science items. Also, we have discussed preliminary results from two investigations in which illustrations are being developed or examined according to the conceptual framework.

Available evidence from those studies shows that the framework allows to systematically design illustrations for science test items and to develop a coding approach for examining the visual makeup of illustrations. Available evidence also indicates that the coding system we have developed to analyze the features of item illustrations is sensitive to important differences between science illustrations used in China and in the U.S. Illustrations used in science tests in China tend to have more graphic elements than illustrations in science tests in the U.S.

As discussed, the proposed conceptual framework provides test developers with a conceptual tool for examining and systematically generating illustrations in science assessment.

Notes

Note 1. While in the U.S. large-scale science tests are administered in eighth grade for all science content areas, in China large-scale tests are administered in eighth grade for Earth and Space Science and Life Science, and in ninth grade for Physics and Chemistry.

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