

Layered Inscriptions:
Do They Bridge the Gap between World and Language?

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RUNNING HEAD: Layered inscriptions

Layered Inscriptions: Do They Bridge the Gap between World and Language?

Abstract

Inscriptions have been the central mediating element in the development of science. They also figure prominently in school science textbooks. However, research suggests that students do not easily understand inscriptions. This may be due to the gap between them and the things in the world that they stand for, which requires tremendous work of the reader. There have been suggestions that overlaying an experience-distant inscription with one that is closer to everyday experience will help students learn. The purpose of this study was to investigate the function of layered inscriptions in middle school science textbooks, which we found to occur 20 and 24 percent of inscriptions in Korean and North American science textbooks, respectively. In this study, we develop a semantic model that allows us to describe the work of reading and interpreting layered inscriptions. Our analyses of several layered inscriptions articulates the tremendous amount of work that needs to be done to establish the links between the layered inscriptions, and between the inscriptions and the world familiar to the student. In addition, different functional relations in layered inscription require different kind and amount of linking work. Our study shows that although layered inscriptions decrease the gaps between more experience-distant inscriptions and the world of experience, the total number of different types of work (structuring, transposing, and translating) to be done and aligned increases. Our study provides a framework for studying how students learn from using inscriptions in general and layered inscriptions in particular.

Inscriptions are perhaps the most salient feature of science, both in its processes, where inscriptions are created, and its products, such as the inscriptions that appear in published articles and textbooks (Lynch & Woolgar, 1990). Historically, inscriptions constituted resources that allowed science to evolve into the form that we know it today (Edgerton, 1985). It therefore does not come as a surprise that inscriptions are important features of school science textbooks (Roth & McGinn, 1998). But it is surprising that students find it difficult reading and understanding inscriptions (Schnotz, 1993), for one would expect schools in general and science teachers in particular to focus on inscription-relevant literacy skills (Roth, 2002). It would be too quick, however, to fault students or their teachers for these problems.

Close analyses of inscriptions in high school textbooks showed that reading inscriptions such as graphs (Roth, Bowen, & McGinn, 1999) or photographs (Poizzer & Roth, 2003) and integrating them with textual information requires a tremendous, perhaps insurmountable amount of work. On the one hand, students may not have had the resources for doing such work; on the other hand, textbook authors may not have done enough to facilitate doing this work. How might textbook authors facilitate students' efforts in reading inscriptions? A hint for how this might be achieved comes from research on the use of inscriptions in computing environments (e.g., Roschelle, 1992; Roth, Woszczyzna, & Smith, 1996). These studies showed that inscriptions of different types presented simultaneously on top of one another, such as simulated objects and vectors that represent force and velocity, mediated the learning of kinematics. Questions seem to impose themselves: "How might the layering of inscriptions provide students with resources in learning science from textbooks?" and "Why might any such mediation occur?" For example, one might ask, "What is the work of reading required to understand an inscription that layers a graph displaying Boyle's law, naturalistic renderings of pistons, and force arrows?" (Figure 1); and "What does the layering do that other forms of inscriptions do not achieve?"

We begin by answering the question, "What work is required for reading these inscriptions?" The text accompanying this figure indicates that the figure represents the relationship between the volume and pressure of a gas, that is, Boyle's law. Boyle's law is articulated in terms of the

statement “at the same temperature, the volume of same amount of gas is inversely dependent to the pressure” and the equation “ $P * V = k$.” The figure itself presents a graph, seemingly torn from a textbook, superposed by two different types of inscriptions. First, there are naturalistic drawings rendering grey weights (or pistons) in a green but apparently transparent beaker. Second, there are three yellow and orange arrows of different length positioned above each beaker-piston combination. Fine arrows in black begin each at a different point on the graph and point to one of the three beakers. The stated purpose of the inscription is to allow students to learn Boyle’s law (as in the mathematical inscription $P * V = \text{const}$), embodied in the graph; not stated is the fact that students need to ground the inscription in their lived experience and understanding of how the world works. What is the work of reading required to relate this layered inscription to one’s lived experience, and therefore to learn from reading or interpreting this inscription? How does this work differ from other circumstances that either state Boyle’s law simply in its mathematical or in mathematical and graphical form?

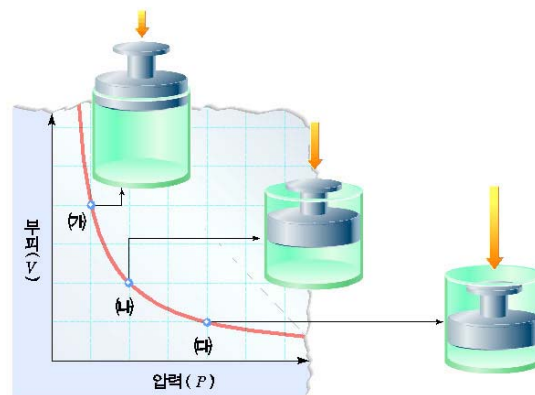


Figure 1. This example of a layered inscription was taken from a Korean seventh-grade textbook in the section on Boyle’s law. The label on the ordinate is “volume (V)”; the label on the abscissa is “pressure (P).” The letters on the graph are “a,” “b,” and “c,” respectively, from top left to bottom right. From Lee, Chae et al., 2000, p.116, reprinted with permission)

At a global level, the inscription was designed to mediate students’ learning of Boyle’s law, normally stated in the form of “ $P * V = k$,” and often expressed in terms of a graph. The beaker-

piston combinations and yellow-orange arrows are additional resources that potentially mediate between the more experience-distant equation and graph and the experientially nearer beaker-piston combination. Although this inscription might look easy to the science educator (teacher) who already knows it and knows about Boyle's law, it is rather complex requiring work that is hidden.

Our initial textual presentation of the inscription already articulates the first type of work to be done. That is, at a global level readers have to perceive the three types of inscriptions as separated yet connected inscriptions, constituted at the micro-level by colored dots on the page: the red graph on light-blue lined paper, grey pistons in green beakers, and yellow-orange arrows. At a more fine-grained level, readers have to articulate, for example, the green areas as beakers and the grey areas as pistons or weights. Here already we encounter more work to be done: are these grey entities generic pistons or are they specific weights? More work is required, for example, in the form of comparing the three beaker-piston combinations, which is work within the same type of inscription. Comparing the three pistons reveals that they are equal in size; they are, however, inserted into the beaker at different depths. In fact, for our reading to take us to Boyle's law, we need to see (perceptual work) the amount of space left on the bottom of the beaker rather than how far the piston has descended into the beaker. That is, if they do represent weights, then our experiences suggest them to be of the same weight—unless they were made of different materials (which requires experiences with and understanding of density). Perceptual structuring further reveals that the three pistons are inserted into the beaker at different heights. Comparison (work) of the different heights with the sameness of the grey parts suggests the latter to be generic pistons (same weights) rather than different weights that would require special attention.

These are only drawings of beakers and pistons. Work is required to see the grey part of the drawing *as a* piston, the green parts of the drawing *as a* transparent beaker, that is, work is required to relate the drawings to corresponding things in the world we know so well. Even such apparently simple relations between a drawing of a thing and the thing that it denotes—iconic

relations in the language of semiotics—are learned and culturally specific. They require previous experiences with such things as beakers and pistons (or weights) and with cultural conventions regulating the relationship between drawings and the things they depict.

Perceptual structuring (work) reveals that the color of the broad arrow changes from yellow at the tail to orange at the tip. Within-inscription-type *comparison* (work) reveals that the three arrows have the same width but are different in length. Between-inscription-type comparison (work) is required to produce the inverse relation between the length of the arrow, on the one hand, and the distance of the piston from the bottom of the beaker, on the other hand.

Perceptual structuring distinguishes the paper and grid (here blue) from the graph proper, here black axes and red line. The black lines are not just axes but, as indicated by the arrows, are ordinate and abscissa of a grid system where distance from the intersection is equivalent to magnitude. Thus, although not specified in the inscription, a relationship to algebra and the size of numbers needs to be made. The red line has to be articulated (work) as part of this grid rather than of other parts of the inscription. It moves from top left to bottom right in a smooth curve. Each point has to be constructed (work) as a couplet relating a particular value of volume and pressure. (This also requires “pressure” and “volume” to be associated with abscissa and ordinate, respectively.)

On the red line, there are three blue circles; these require perceptual structuring as points of the red line. Black arrows are drawn from each of these points to one of the green beaker-piston combinations, two pointing to the sides, one to the bottom of a beaker. If the drawings are to assist in learning, the student needs to do multiple relation work: (a) for each point, relate the length of the yellow-orange arrow to the distance of a graph point from the origin along the ordinate, and relate the height of the piston above the beaker bottom to the distance of the point from the origin along the abscissa; (b) relate these relations to one another.

The black arrows do not link each member of a couplet (p , V) to the corresponding height above the bottom in the beaker and the yellow-orange arrow, but generically point to the beaker. This may increase the amount of relational work that has to be done by the reader. That is, the

reader needs to perceive each point as having its own value of p and V , and link those to specific features of the beaker-piston combination and to the yellow-orange arrow. Careful comparison is required to link the p -values (distances of graph points from the origin along the ordinate) to the lengths of the yellow-orange arrows, and to link the V -values (distances of graph points from the origin along the abscissa) to the heights of pistons above the beaker bottom. The comparison among these links will reveal to the reader that there is an inverse relation between p -values and V -values, both in the graph points and in the arrows and beaker-piston drawings.

This inverse relation—Boyle's law—should be related to the reader's real experiences. Readers may, or may not, have pushed and pulled or released a piston inserted in a syringe (beaker) or have used a bicycle pump closing its end with a finger. If they pushed the piston more forcefully, the distance of the piston from the bottom of the syringe would decrease more, as the pressure on the piston would change the volume of gas trapped inside of the syringe. These experiences could then be linked to the drawings of the piston-beaker combination and the accompanying three arrows, and to the graph representing Boyle's law. In this way, the drawings (arrows) could bridge the gap between the graph (inscription) and the real world. The question is, however, what do readers relate the layered inscription to if they did not have this prior experience?

This study was designed to describe the reading work required to understand inscriptions in general and layered inscriptions in particular. We articulate the work in terms of a semantic model that makes salient the different types and amounts of work required to the interpretation of an inscription. We provide several analyses of different types of layered inscriptions to exemplify what science educators and textbook writers have to consider when preparing layered inscriptions for student use.

Background

Inscriptions

Over the past two decades, educators increasingly have become interested in inscriptions, a theoretical notion categorizing all forms of representations other than text including drawings, maps, diagrams, and mathematical equations (Roth & McGinn, 1998). Inscriptions can be ordered according to the amount of information that they are made to encode, which is roughly equivalent to the amount of work required to get to them through transformations of the raw material (Latour, 1999). Thus, a photograph constitutes an iconic, mechanical rendering of a situation, which is closer to experiencing the situation than a naturalistic drawing, in which a lot of detail has already been omitted (Pozzer & Roth, 2003). A graph depicting the depth distribution of different types of soil requires many transformations, such as collecting samples with a soil corer, identifying soil types at different heights in the sample, mapping vertical distribution against horizontal distances between sample sites, and so forth. At the same time, the graph summarizes more information than, for example, a photograph or a physical rendering of one soil core. This graph, although material in itself, is therefore much farther from the originally experienced situation and its soil distribution than the photograph or the physical representation (Latour, 1999). However, the scientific value (power) of an inscription derives exactly from the distance it has from the individual situation: the more situations it can describe the more powerful it is (Latour, 1987). For this study, several important issues arise from this character of inscriptions: there is a multiplicity of inscriptions pertaining to the same phenomenon, this multiplicity has both ordered (cascade) meaning, and along the cascade, inscriptions are characterized by their distance from the original phenomenon.

This distance between an inscription and the thing it stands for has been related to the difficulty involved in connecting the two, that is, in interpreting an inscription (Roth, Bowen, & McGinn, 1998). This difficulty may be due to the fact that interpretation requires an amount of work equivalent to this distance. One might assume that multiple inscriptions of different types

used simultaneously help in interpreting, because they can be thought of providing bridges between the most experience-distant and most scientific, on the one hand, and the original phenomenon, on the other. However, the word is yet to come concerning the value of multiple representations. Some research suggests that multiple representations help (van Someren, Boshuizen, de Jong, & Reimann, 1998), whereas other studies report problems that learners experience in integrating multiple inscriptions (de Jong et al., 1998; Scanlon, 1998).

Past research has focused predominantly on multiple but distinct inscriptions. Few studies have actually investigated situations in which inscriptions of different types are integrated into one. The two studies that we are aware of investigated computer software, in which animated drawings of everyday objects (e.g., balls, walls) also contained different kinds of arrows, themselves inscriptions standing for velocity and force, both of which are modeled by vectors (Roschelle, 1992; Roth, Woszczyna, & Smith, 1996). Both studies suggested that this layering of animated diagrams (nearer to worldly experiences with moving objects) and diagrammatic renderings of velocity and force in the form of arrows (farther from the experience of moving objects) helps students in learning physics. Does the association of inscriptions such as graphs and vectors with more experience-near inscriptions such as naturalistic drawings and photographs facilitate their interpretation? What is the interpretive work required? As part of this study, we developed the following model that articulates the semantics of interpreting multiple (layered) inscriptions.

Semantic model of multiple (layered) inscription

We began the construction of our semantic model with existing studies concerning interpretation of inscriptions. The work of moving from one type of inscription to another type of inscription is called a translation; the work of moving from one to another inscription of the same type is called a transposition (Janvier, 1987). Examples of translations include the construction of a graph from a table, or the interpretation of a graph, which requires its translation into a verbal description; examples of transpositions include the creation of one graph from another or

the creation of an ordered data table from an unordered one. Unnoticed by most educators is the fact that translation and transposition require the existence of equivalent structures—different natural phenomena are articulated whether the height or slope of a graph is salient to the interpreter (e.g., Leinhardt, Zaslavsky, & Stein, 1990). That is, to understand interpretation researchers also need to attend to the perceptual structuring of inscriptions (and natural phenomena) from their raw material, the colored traces on paper or colored dots on computer monitors (Roth & Bowen, 2003). These three types of work, structuring, transposing, and translating constitute the basic elements (types of work) of our semantic model (Figure 2), which we exemplify by returning to our introductory inscription concerning Boyle’s law (Figure 1).

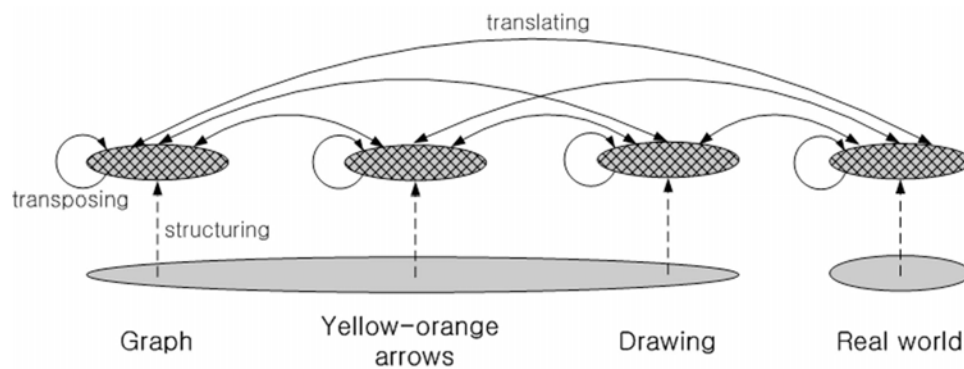


Figure 2. Semantic model of reading the layered inscription in Figure 1. Each arrow denotes work to be done in reading this inscription: structuring (dotted arrows), transposing (circular arrows), and translating (curved line arrows). The progression from left to right is from more experience distant to more experience near inscription, and experience (world) itself.

Inscriptions (graph, arrows, drawing) and the real world experience of the reader are represented by two ovals (Figure 2). The lower oval (the elongated gray circle) refers to the material basis of an inscription, that is, the colored ink dots that constitute Figure 1. The upper oval refers to the structure that appears in the perception of the interpreter. To be able to make the required connections implied, this material basis has to be structured by the reader into a set of inscriptions with internal equivalent structures that can be linked—such equivalent structuring of educational materials on the part of the student cannot be taken for granted and often is not the case (Roth & Duit, 2003). How these ink dots appear to the reader depends on the structuring

work. In the introductory example, the overall structuring into separate inscriptions is facilitated by the use of distinct colors associated with each inscription—blue for the paper, red for the graph, orange for the arrows, green for the cylinder, and grey for the piston. In our model (Figure 2), the different structured domains (upper level ovals) are ordered constituting a chain of references: from the most experience-near on the right, lived experience in the world characterized by its local, particular, and continuous nature, to the most experience-distant on the left, here graphs, characterized by increasing non-local, standardized, and universal character (Latour, 1999).

Arriving at a separation of the same material basis into the intended cascade of inscription does not mean that students will arrive at the required internal structuring of each inscription. In Figure 1, for example, a person might perceive a piston or a weight; and the reader might perceive the piston as going a certain distance into or as being a certain distance from the bottom of the cylinder. These are different ways of perceiving the same material configuration. In each case, what the reader perceives has emerged as the result of structuring work. Most frequently, structuring is automatic so that we do not attend to. But when readers of inscriptions experience problems, they may say to themselves something like, “I have to look at it in a different way”; in this, they explicitly referred to the work of structuring the raw materials before them (Roth & Bowen, 2001). There is evidence from the study of scientists that the structured ways in which they come to look at a natural phenomenon and the mathematical structures that they evolve as part of their research emerge jointly (Roth, in press).

Perceiving the different piston-cylinder configurations as different states of the same piston and cylinder ensemble requires the work of transposition (circular arrows in the model [Figure 2]). This work is facilitated here, because the three different configurations are available and therefore can be more directly compared than if the reader had to imagine such a change. A translation is required in going, for example, from the value of pressure at a particular point to the length of a yellow-orange arrow. The work of translation occurs when a reader makes a relation between the changing height of the three pistons above the cylinder bottoms and the

changing volumes on the graph. Another translation is involved when readers make links between the drawing of the pistons and their real world experiences with pistons. Series of translations lead to the understanding of relation between inscriptions and, ultimately, to the understanding of scientific content that all inscriptions refer to together. For example, in Figure 1, a person might come to understand the relation between the pressure and volume, Boyle's law, both within a inscription (e.g., graph) and between inscriptions (e.g., arrows and drawings) and real world (e.g., his experience of syringe with piston).

Our semantic model articulates the layering effect in two ways. First, there is one material basis making all inscriptions appear in the same plane. Second, when we look at Figure 2 from the right side, all structured inscriptions come to be aligned so that between the real-world experience and the graph appear two other inscriptions, the drawing and arrows. In the present study, we focus on the role of the intervening inscriptions, which potentially play a mediating role, allowing readers to bridge the gap between lived experience and graph.

Study Design

This study is concerned with the work required for reading layered inscriptions, which are prevalent in Korean science textbooks for middle school students (see below). In our study, we drew on the precepts of interaction analysis to conduct our collaborative analysis (Jordan & Henderson, 1995) and on the precepts of fourth-generation evaluation to establish its quality (Guba & Lincoln, 1989).

Selecting the textbooks and classifying inscriptions

We selected two Korean grade-seven science textbooks that are most frequently adopted in the country (Lee, Chae et al., 2000; Lee, Hur et al., 2000). Grade seven science covers four science disciplines: physics, chemistry, biology, and earth science. In the seventh National Education Curriculum of Korea, which was instituted by the government in 1997, a variety of inscription are presented to students for the first time *and* in color. Until the sixth National

Education Curriculum (1992–1997), all textbooks had made use of black-and-white inscriptions, with the exception of a few introductory pages of each textbook. For a comparative analysis, we also selected a representative North American science textbook at the seventh grade level: Science Probe 7 (Bullard et al., 1997) is the most frequently adopted science textbook in British Columbia, Canada.

For the classification of different inscription types, we followed the scheme proposed in a recent study on this topic (Pozzer & Roth, 2003). We considered an inscription to be layered when there were two or more types (genres) of inscription co-deployed in the same physical space on the page and co-thematic (i.e., that are about the same thing) but not when they were simply co-generic (i.e., that are of the same genre, type). We then identified all layered inscriptions in the two Korean textbooks, which amounted to 320 out of the total of 1616 inscriptions (19.8%), and in the Canadian textbook, which amounted to 114 out of a total of 468 inscriptions (24.4%). These 434 layered inscriptions constituted the sample for our analyses.

The analyses were conducted in videotaped, collaborative sessions to finding and classifying examples of layered inscriptions and in developing our semantic model. We repeatedly refined the criteria for identifying and classifying layered inscriptions. To assist in this task, copies of inscriptions were made and placed in a pile. This pile was then sorted into different, emerging categories. We began by providing initial verbal descriptions for each categories and articulated our personal reasons for classifying an inscription in one rather than another way. Each problematic case was discussed until we arrived at a common way of classifying all inscriptions consistent with our verbal description of a category (resulting in Table 1 discussed below). Our joint analysis meetings were recorded in order to capture levels of progressive subjectivity and construct an audit trail, both of which are important criteria for establishing the quality and credibility of qualitative research (Guba & Lincoln, 1989). We also generated and revised our semantic model in collaborative sessions. This model, in turn, provided us with the basis for further refining the identification and classification of layered inscriptions in our sample.

The Work of Reading Layered Inscriptions

This study was designed to understand the work that readers have to do to relate experience-distant inscriptions to their own lived experience. We were particularly focusing on the role of additional inscriptions layered on top of the target inscription. Our initial analyses made it clear that there were differences between layered inscriptions. Because there is a possibility that these differences would lead to different kinds and amounts of reading and interpretive work to be done, we constructed a classification scheme covering every instance in the sample ($N = 434$). We begin by articulating the classification scheme and then provide descriptions for the work required by four different types of inscriptions. We selected these four examples as representative of our sample, simultaneously showing one or more kinds of layered inscriptions.

Classification of Layered Inscription

The criteria we arrived at for the classification of layered inscriptions are based on the function that additional layers have with respect to the main, target inscription. We arrived at 11 such functions, which we captured in the following category names: Simple (no apparent function), worksheet, background, analogy, data-presentation, magnification, sequencing, systemic relation, comparison, filter, and explanation. Table 1 presents our final categories with brief definitions and the frequency of occurrence. Each functional relationship presents a different kind or amount of reader's work necessary to make sense of a layered inscription. In addition, the categories are not mutually exclusive, because we can find several cases of layered inscriptions (32 cases) that have two or three functional relationships. For example, one of the figures discussed below (Figure 5) includes both analogical and explanative layer. In that case, the inscription was classified and counted as analogical, as this relationship appears to be the most important for arriving at the required interpretation. However, for the purpose of reporting the frequencies of each functional relationship, we re-counted all relationships. For example, Figure 5 is counted twice as analogical and explanative: The numbers in *italic* on Table 1 shows the results of these re-counting.

Table 1. Categories of layered inscriptions, their descriptions and frequencies

Categories of layered inscriptions	Descriptions	Frequency Count (%)	
		Korean (<i>N</i> = 320)	North American (<i>N</i> = 114)
Simple	Two or more inscriptions are just layered together. There seems to be no important relationship between the inscriptions.	31 (9.7) <i>31 (9.0)¹</i>	4 (3.5)
Worksheet	Two or more inscriptions where part of them should be filled in by the reader, thus becoming layered inscriptions. Empty spaces are provided where the reader should draw on something. ²	15 (4.7) <i>18 (5.2)</i>	0 (0.0)
Background	Two or more inscriptions where one of them serves as a background to the other, providing specific contexts.	32 (10.0) <i>34 (10.1)</i>	7 (6.1)
Analogical	Two or more inscriptions where the relationship between inscriptions is analogical to one another.	12 (3.8) <i>12 (3.5)</i>	1 (0.9)
Data-presenting	Photographs or drawings are inserted in a table as examples of phenomena.	6 (1.9) <i>6 (1.7)</i>	3 (2.6)
Magnification	One or more inscriptions show precisely the relevant part of the other inscription, through magnification. Sometimes the magnified parts give the readers more detailed information, especially in biology.	50 (15.6) <i>54 (15.7)</i>	11 (9.6)
Sequence	Each inscription represents one step or the result of an experiment or activity. Sometimes, this takes the form of time-series presentations.	18 (5.6) <i>20 (5.8)</i>	21 (18.4)
Systemic relations	Diagrams and systems that have arrows representing movement or causal relationship. Diagrams depict the mechanism or the flows with arrows layered on top of another inscription. Systems are causal models, so they represent both the entities (natural objects or phenomena) and their relationships with arrows, lines, or words.	48 (15.0) <i>54 (15.7)</i>	32 (28.1)
Comparison	Two or more inscriptions present phenomena to be compared to each other.	25 (7.8) <i>32 (9.3)</i>	12 (10.5)
Filter	Photograph with a drawing that has undergone some “filtering” (Lynch, 1990). Figure 7 contains filtered layer.	7 (2.2) <i>7 (2.0)</i>	2 (1.8)
Explanation	Two or more inscriptions that explain the topic (contents, principles, models, and natural phenomena) together.	76 (23.8) <i>85 (22.0)</i>	21 (18.4)

Note 1: The numbers in italic refer to frequencies of all relationships in 320 layered inscriptions from the Korean textbooks, for example Figure 5 have both analogical and explanative relationships.

Note 2: In Korea, students own their textbook, so they can write directly into the textbook.

The most frequent layered inscriptions are explanations in Korean textbooks (24%), and systemic relations in North American textbook (28%). Simple and magnification layers have a higher frequency in Korean textbooks, while sequence layers are more frequent in North American textbook. For background, data-presenting, comparison, filter, and analogical layers, the relative occurrences are similar in the Korean and North American textbooks (less than 5 %). In addition, there were no worksheets layers in North American textbook inscriptions.

In the subsequent sections, we exemplify and discuss these functional relationships with four layered inscriptions, including background, analogical, data-presenting, and explanation layers. We chose these four inscriptions because they cross categories by include multiple layers, which allowed us to exemplify a maximum number of functions with the least number of examples. Thus, the example of background layers also contains magnification and comparison dimensions; the subsection on analogical layers contains explanatory dimensions; and the example of data-presenting layers also contains filter and comparison. Before proceeding, however, we provide the following commentary on special inscriptions. Simple layered inscriptions are layered images that are combined together using resources, such as, for example, computer software programs that allow the superposition of two images. Although no other relationship between the layered inscriptions is evident, each inscription is somehow related to the text (at least evident to those readers who are familiar with the domain). The layering of these inscriptions does not produce or multiply additional meaning that would exist by layering inscriptions together. Therefore, this kind of layered inscription constitutes a sort of exception in our scheme because it does not require translation between the constitutive inscriptions.

Many explanatory diagrams or schemas with arrows that represent the flow of materials through various organs are used in biology-related sections of the textbooks (systemic relations). The organs are conventionally depicted in cross-sectional perspective, onto which arrows are layered to articulate the movement of, for example, nutrients. The arrows soften the static character of the image (Bastide, 1990). This kind of layered inscription can be considered as being layered *inside* another inscription, whereas other categories of layered inscriptions present an inscription layered *outside* another.

Background Layer

Background layered inscriptions include layering situations in which one inscription serves as a background to another, therefore providing specific contexts with which another inscription can be read. The content of the background inscription is related to the topic of the main

inscription, which can be, for example, a table, pie chart, graph, drawing, and so on. An example of a background layer can be found in Figure 3: readers are to learn from this inscription that the weights on these two celestial bodies are different, because of the difference in the gravitational forces of the earth and the moon, but that the masses are the same. To arrive at *this* lesson, the learner has to do very specific types and amounts of work, which we articulate in the following.

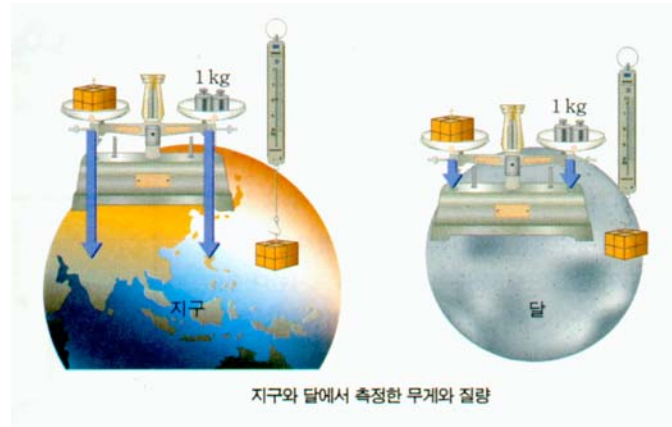


Figure 3. Example of background layered inscriptions. The caption reads “Weight and mass measured on the earth and on the moon” (the letters on the drawing reads “the earth” and “the moon,” respectively, from left to right). (From Lee, Hur et al., 2000, p. 211, reprinted with permission.)

The work of reading Figure 3 is modeled in Figure 4. The inscription in Figure 3 actually contains four different layers. The drawings of two circles are visible, with one of the circles cut horizontally on the bottom. The circles containing the inscription “earth” and “moon,” respectively, serve as background to naturalistic drawings of equal-arm balances and spring scales. Blue arrows are layered onto each side of both balances, beginning at the arms immediately below the pans. The caption associated with the inscriptions reads “weight and mass measured on the earth and on the moon.” The blue arrows and named drawings of two circles are designed to bridge the gap between real world (far right in Figure 4) and the text (caption) (far left in Figure 4) that are experience distant (Latour, 1999). For completeness, our model also includes, as a separate material base, the table featured elsewhere on the page in the textbook and not available in our reproduction of the inscription (Figure 3).

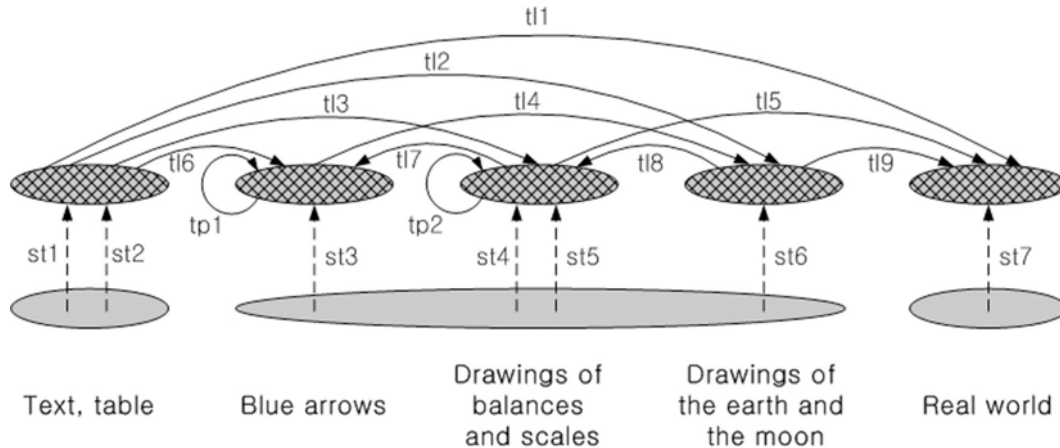


Figure 4. A representation of works required for reading the layered inscription in Figure 3. Each arrow represents the work of structuring ([st], dotted arrows), transposing ([tp], circular arrows), or translating ([tl], curved line arrows).

To unpack this inscription and therefore arrive at what is pedagogically intended, initial perceptual work is required to differentiate the three different layers from the material basis of Figure 3 (elongated circle in Figure 4) followed by the work for structuring, transposing, and translating within and between the layers. Different types of inscriptions to be separated are two circles (left one has orange–white–blue–black colors, and right one has grey color), the naturalistic drawings of balances and scales (with grey and orange colors), and blue arrows (which would not be available in the real equal-arm balances). Two equal-arm balances and two spring scales need to be perceived on top of each circle (that is, translation tl8 [Figure 4]). Equal-arm balances have to be articulated as weighing of “orange cubic things” in comparison with two grey weights placed on each pan (structuring st4 [Figure 4]). The same “orange cubes” are hanging from the spring scales (st5). The two grey weights on the right pan of each equal-arm balance need to be understood as weighing 0.5 kg each, as it can be assumed that together they weight 1 kg (st4). All balances and scales must be assumed as being balanced (st4, st5), being in the final equilibrium state, based on, for example, the fact that the needles perpendicular to the beam of the equal-arm balances are not skewed on either side, providing, of course, that the balances are laid on horizontal firm plane. On this assumption, readers are required to recall previous experiences on weighing things with balances and scales (tl5).

Perceptual structuring further reveals that the “orange cubes” are not just weights but also that they are all the *same* weight on either one of the two equal-arm balances and the two spring scales, which constitute the basis of comparing weights and masses. Comparing scales (tp2 [Figure 4]) on the left and right sides of Figure 3 reveals that the equal-arm balances are balanced similarly, but the spring scale on the left side has a longer string between the weight (orange cubic thing) and the body of the scale than the spring scale on the right side. Perceptual structuring of the blue arrows (within-inscription comparison tp1) reveals that they are all parallel pointing downward with the same length for each one of the two pans of the same equal-arm balance, but with different length between the left and the right equal-arm balances (st3). However, the texts do not state why the lengths of the blue arrows are different in each one of the two equal-arm balances, which would be a cue that leads to learn different weights on the earth and the moon. There is also no explanation of what the arrows stand for, and, consequently, why the arrows are layered on that place, just under the pans of the equal-arm balances, is not evident. Because the arrows have the same blue color, facilitates perceiving them as standing for the same or similar things or phenomena (st3). The function of the blue arrows has to be found while reading other (background) layered inscription, text, and their relationships.

The two drawings in the form of a circle have to be seen as depicting different things (st6). The circle on the left, which is cut horizontally on the bottom, has various colors and lines. Sharp boundaries of different colors have to be perceived as representing different things, that is, the south Asian continent and the sea (tl9 and st7): readers have to resort to experiences with terrestrial maps, whereas the contrasting colors orange, white, blue, and black (which the instructed person knows to stand for ocean, land, etc.) should be ignored, as they constitute structure irrelevant to the pedagogy of the inscription (st6). The word in the center of the left circle, “the Earth,” is consistent with the perception that this circle is in fact representing the planet Earth, with its continents and seas. The circle on the right has to be perceived as depicting the moon, ignoring the strange gray color and texture of this circle, and considering the words “the moon” written inside the circle (st6).

The information provided in the caption of these layered inscriptions is insufficient to explain relations between the inscriptions. Instead, the main text reads “the gravity of the earth pulls the object in a direction perpendicular to the horizontal surface of the earth. ... The magnitude of gravity on the moon is different from that on the earth. ... The weight is different according to the location where it is measured, but the mass is always the same.” The table accompanying the text gives the values of relative gravities on the Earth (1.00), the moon (0.17), Mars (0.38), and other planets. The main text and the table need to be perceived as corresponding to the contents of Figure 3, and to be interpreted (st1, st2), as, for example, they articulate the difference between weight and mass, before they are linked to inscriptions.

All three inscriptions and the text need to be connected to each other, for the reading to take us to what is intended in them. The drawings of the balances and scales, placed on top of the drawings of the earth and the moon (background), have to be perceived as if they were located on the earth (in the case of the drawings on the left) and on the moon (on the drawings on the right) (tl8, tl9). The earth and the moon (background drawings) have to be articulated as that pulling objects towards their surface, but with different gravities (text, table) (tl2). The blue arrows have to be related to the different gravities and their lengths to the different gravitational forces of the earth and the moon (table) (tl4, tl6). In addition, the sameness of the equal-arm balances and the difference on the spring scales have to be translated into the text; the spring scales have to be linked to weights and the equal-arm balances to masses (tl3).

These relations have to be linked together in a form of a sequential translation. That is, the balances and scales (naturalistic drawings), located on the earth or the moon (background drawings) where gravity is different (text and table), have arrows (drawings) with different lengths (tl7), representing difference in gravity (text and table). Furthermore, the difference in the weight occurs only in the spring scales (naturalistic drawing) in different locations (background drawing and text), so that weight (measured by the two spring scales) is related to gravity, whereas mass (measured by the two equal-arm balances) is not. Although most readers

might not have experienced weighing things on the moon, the background drawings and the arrows must be used in imagining such situation on the moon (t15, t19).

In the process of reading Figure 3, readers have to rely on previous experiences with cultural conventions regulating the relationship between inscriptions and the things they depict. For example, the different, reduced scale (ratio) between the drawings of the balances and scales and the earth and moon must be interpreted as the result of a zooming process (This translation work correspond to the magnification dimension). The relative size (diameter) of the earth and the moon is different from the real proportion (the moon is 1/4 of the size of the earth). In addition, no arrows are perpendicular to the surface of the earth or the moon. These perceptions have to be ignored, as they constitute, from the perspective of someone who already knows, trivial limits of inscriptions (t18). Alternatively, teachers should be aware of these possible confusing problems related to reading inscriptions. Furthermore, the blue arrows are placed only on the equal-arm balances. The two spring scales have no arrows, which could otherwise have helped readers to see the difference between the two spring scales, as the lengths of the arrows (gravitational forces) would be different. Nevertheless, if these background drawings and arrows were not used, readers could be perplexed to see the same spring scale measures the same object differently. The background drawings and the arrows are resources that provide context to the different balances and scales, thus potentially helpful to readers in making sense of the different contexts of measurement (t11).

Analogical Layer

As their name indicate, analogical layers present a perceptual analogy, intended help reading inscriptions and learning the lessons the inscriptions refer to. In Figure 5, the photograph of the hailstones and a broken windshield constitute an analogy for air molecules that have hit the inside of a balloon. The stated purpose of the inscription is to allow students to understand the pressure of a gas as the result of the collision of air molecules into the wall of a vessel. Figure 6 shows the work of reading Figure 5 required for achieving the intended pedagogical purpose of

the inscription. The filled balloon, which is the macroscopic phenomenon (far right in Figure 6), is to be explained by the collision of invisible molecules on the balloon's wall, represented on molecular diagram. The microscopic world (far left in Figure 6) is also intended to be constructed with molecular diagram and its analogous photograph.

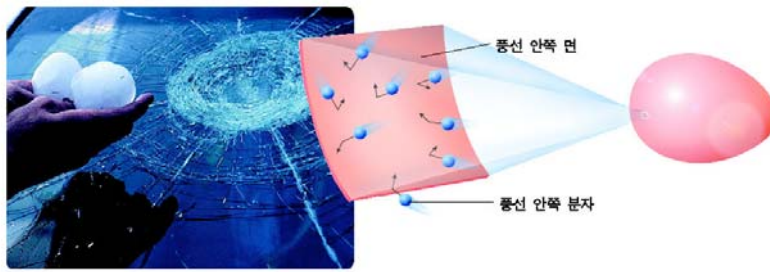


Fig 11 The collisions of molecules. The molecules of gas inside a balloon collide with the wall of the balloon, in the way the hailstones collided with the windshield of a car, causing an impacting force.

Figure 5. Example of analogical layered inscriptions. The letters on top read “inside wall of the balloon” and at the bottom read “molecules inside the balloon.” (From Lee, Chae et al., 2000, p.113, reprinted with permission. The translation of the caption from Korean is ours.)

To learn the intended lesson, initial structuring has to start with the separation of three kinds of inscriptions in Figure 5: Naturalistic drawing of the balloon (right), molecular diagram (middle), and photograph (left). Pale blue lines and shadows between the diagram and the drawing have to be perceived as a magnification process of a small area (white dotted square) of the drawing (the balloon) (t111 in Figure 6). Eight small blue circles with shadows and a black arrow attached to each one of them have to be seen as part of the pink plate that is separated from the rectangular photograph and represents the magnified part of the balloon (st4).

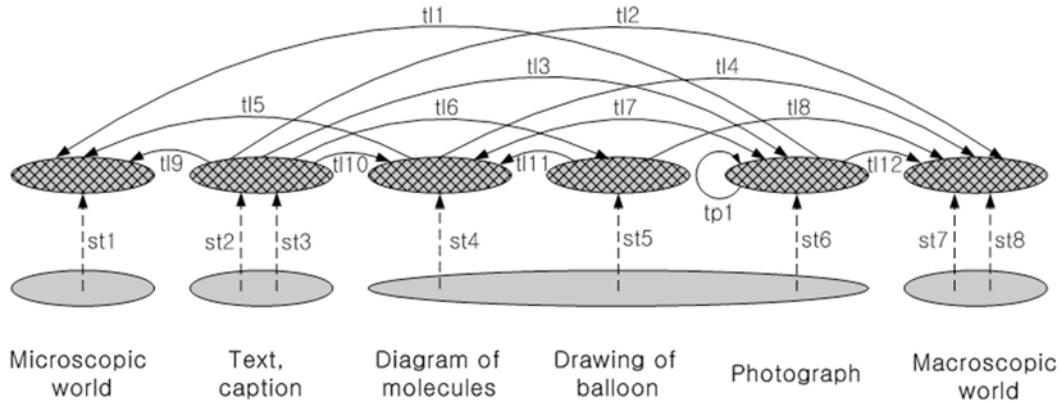


Figure 6. Works required for reading the layered inscriptions in Figure 5. Each arrow represents the work of structuring ([st], dotted arrows), transposing ([tp], circular arrows), or translating ([tl], curved line arrows).

At a more fine-grained level, the drawing of the balloon has to be articulated as an air-filled balloon (st5). The two-dimensional oval shape with pink and white color gradients has to be perceived as a balloon, blown-up and tied at the opening (st5). This color gradient may assist readers to perceptually structure the drawing to include perspective, thought to assist in making the connection with their experiences in the real world (Ackerman, 2002). That is, that the white light reflected on the left frontal area of the balloon would account for such color gradient on the surface of the pink three-dimensional balloon (tl8).

Perceptual structuring of the middle diagram reveals that the pink plate and the small blue (meteor-like) circles are “the inside wall of the balloon” and “the molecules inside the balloon” respectively (st4). Although the letter “the inside wall of the balloon” is connected through a black line to the dark-pink triangular plate, the whole pink plate of rectangular shape has to be seen as a continuous surface (st4). The curved lines of pink plate and white-pink gradient have to be seen as depicting a curved concave surface (st4). Similarly, the seven meteor-like circles inside the pink area have to be seen as “the molecules of balloon inside,” though the corresponding Korean character is connected to the small blue circle outside the pink plate (st4). The blue shadows attached to the small blue circles must be seen as representations of the three-dimensional feature of balls, with tails originated from movement (st4). As such, the tail-like white-blue shadows accompanying every ball should be perceived as depicting the trajectories of

the balls (molecules) inside the balloon. That is, the balls have to be seen as moving in the opposite directions of their tails (st4). Similarly, the broken black arrows have to be perceived as the future trajectories of each ball, although in some case the directions of the past trajectories and the future ones do not parallel to each other. Therefore, the balls must be perceived as colliding into the wall of the balloon at the points where the black arrows are broken, changing their trajectories towards the direction pointed by the tip of the arrows (st4), which perception that leads us to the intended lesson. This perceptual structuring of the middle diagram is consistent with the caption that reads, “the molecules of gas inside a balloon collide into the wall of the balloon” (st3, tl10).

Perceptual structuring of the photograph at right is not self-evident, because the photograph shows a peculiar phenomenon. Most readers, especially who have not experienced such phenomena, have to resort to the caption, “hailstones collide with the windshield of a car, causing an impacting force.” With this caption, readers have to articulate or imagine the photograph as a car windshield broken by the falling hailstones (st3, tl3). Within-inscription comparison (tp1) reveals that the sizes of the two big hailstones are about half of what is assumed to be an adult’s hands, and they are similar in size and shape to the inner circle left on the broken windshield which is produced really with falling hailstone (st6). The blue color of windshield has to be seen as the refracted color of the sky (st6). If the readers have had such experience, they would be able to notice that the special characteristic of the car windshield glass does not allowed it to crack sharply, what might produce the white circle-shapes when hit by the hailstones (tl12).

The three kinds of inscriptions have to be linked (translating work) to each other, to the text, and to the real (macroscopic and microscopic) world. The pink plate of the diagram has to be related to the drawing of the balloon, as it depicts the enlarged (and flipped over) part of the balloon inside (tl11). Readers have to articulate that this magnifying or zooming is an imaginary process different from the processes in usual optical instrument such as telescope or microscope (tl5). We cannot see the molecules of air inside the balloon, and we cannot slice the wall of a

balloon in the way it is schematically represented in the diagram. Readers are asked to see the air molecules inside the balloon, from a microscopic viewpoint (tl5). Thus, the relationship between molecular diagram and drawing of balloon is a kind of explanatory layer.

The photograph and the diagram have to be linked through an analogical relationship. This analogical translation between them requires much work. There are few similarities between the photograph and the diagram (except for the circular shape of both the hailstones and the blue molecules). The words “in the way” in caption have to be used as a clue of translating analogically from the photograph to the diagram, and from the diagram to the photograph. That is, this translation is bi-directional (see the arrow of tl7). The hailstones have to be mapped on to the air molecules, and the (outside) car windshield must be mapped on to the (inside) wall of the balloon (tl7). These mappings are rather explicit or direct in a sense that they can be done by relating those elements of two inscriptions only with the surface features of two figures. In addition, another kind of mapping, implicit or hidden, has to be made, such as mapping the moments of collisions in each inscription, or the mapping of the impacts of those collisions (tl7). This last mapping is the most important aspect of the work for understanding “pressure” in a microscopic sense. That is, the movement of the air molecules has to be articulated as it results in molecules’ collisions into the inner wall of the balloon, and also results in the impact of forces on the balloon’s inner wall (tl7).

These translations (mappings) can be affirmed while reading the text. Following the figure, the main text states, “the molecules inside the balloon move around freely, colliding continuously against each other and against the wall of the balloon. The balloon becomes swollen by the impact force exerted by the collisions of the molecules against the wall of the balloon.” Some part of the main text has to be structured before they are linked to the layered inscriptions (st2). For example, readers must imagine the situation in which two molecules collide against each other, because such collisions between molecules are not depicted in the inscription (tl5). With the main text, it has to be concluded that the impact forces of the collisions

of the molecules against the wall of the balloon is like the one of the hailstones crashing on a car windshield (tl9, tl1), and that such forces make a balloon swollen (tl2, tl6).

Translating between layered inscription and real world is a two-fold process in Figure 5. The real world has to be seen (st1, st7, st8) as existing of a macroscopic world that has microscopic aspects accessible only by means of mediating tools and instruments. In addition, two kinds of macroscopic world experiences of the readers have to be activated: experiences with a air-filled balloon and with hailstones (st7, st8). The drawing of the balloon has to be related to the experience with the air-filled balloon (tl8), and the photograph of the hailstones has to be related to the experience with hailstones, or it has to be used to foster imagination of the hailstones falling (tl12). The microscopic world has to be constructed by readers in relation to the diagram (st1 and tl5). The construction of the microscopic world (view) could be assisted by the analogous photograph and related to real world experience with hailstones. However, at the same time, readers have to ignore some other kinds of analogical relationship that may exist between the photograph and the diagram. The mapping might be done between structural features of the two inscriptions, which are not relevant to the scientific concept being presented. For example, the hailstone always falls downward whereas molecules move in all directions. Therefore, these irrelevant mappings have to be distinguished from the relevant and ignored (tl7).

In sum, the drawing of the balloon (the macroscopic phenomena) has to be linked with the diagram (the microscopic world) with the aid of the analogous photograph and the main text. The analogical layer between photograph and diagram, and the explanatory layer between diagram and drawing have the potential to help readers associating the macroscopic phenomenon with the microscopic viewpoint (tl4 and tl5), which is one of the most important concepts in chemistry.

Data-presenting Layer

Data-presenting layers often consist of tables in which several cells are filled with photographs or drawings as examples of phenomena. Figure 7 is a table of six major rock-forming minerals. This table is a complimentary resource located at the end of the unit on the

topic of “identification of minerals and their properties.” No more explanation is provided about the contents of this table. Six kinds of minerals are tabulated with their appearances, colors, split types, hardness, and crystal forms. The row of appearance is filled with photographs of each mineral, and the row of crystal form with diagrams depicting the shape of crystal that constitutes each mineral. Because the textbook authors constructed the tables, these do not have the authentic quality of a photograph (Bastide, 1990). Therefore, the photographs inserted in a table can add more authenticity to the table.

	석영	장석	흑운모	각섬석	휘석	김람석
모양						
색깔	무색	흰색	검은색	녹갈색	녹흑색	황록색
포개짐	없음	두 방향	한 방향	두 방향	두 방향	불규칙
굳기	7	6~6.5	2.5~3	5.5	5~6.5	6.5~7
결정모양						

Figure 7. Example of data-giving layered inscriptions. The table summarizes the properties of six rock-forming minerals including, from left to right, quartz, feldspar, biotite, hornblende, pyroxene, and olivine. The rows are, from top to bottom, appearance, color, split type, hardness, and crystal form. (From Lee, Chae et al., 2000, p.63, reprinted with permission.)

In Figure 7, photographs and diagrams enliven the table, which would be otherwise in the form of an aggregation of words and numbers. The work of reading Figure 7 is modeled in Figure 8. This layered inscription is intended to teach students to identify six kinds of minerals and compare their properties. The photographs are more experience near (right in Figure 8), and diagrams and properties of words and numbers are more experience distant (left in Figure 8).

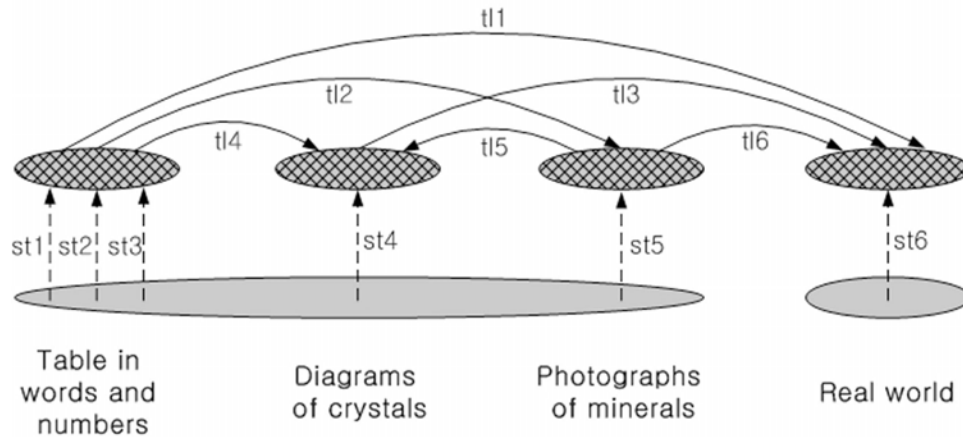


Figure 8. Works required for reading the layered inscriptions in Figure 7. Each arrow represents the work of structuring ([st], dotted arrows), or translating ([tl], curved line arrows).

At a general level, Figure 7 seems to consist of three or more tables. The top row has six brown rectangular shapes containing text; the next row presents six rectangular photographs and one pale blue rectangular shape with rounded extremities (left side), with textual information inside. Under these rows, a black rectangle includes six columns and three rows, filled with letters and numbers, plus three circles with different colors and shapes, again containing written information. In the bottom row, six diagrams are inside a black rectangle and one pale violet rectangular shape with rounded extremities is placed outside, on the left side. The two black rectangles are divided by white line inside of them, while two rows on top separate their cells with narrow spaces. However, Figure 7 must be perceived as *one table* with two dimensions of columns and rows: The six brown rectangles on the top row name each column, and the two rectangular shapes at the top and bottom of the first column, plus the three circles in between, name each row. That is, when one reads the rows in one column, he or she has to assume that one dimension (the column) is constant (st1 to st5 in Figure 8). For example, the column under the first brown rectangle, which consists of a white–blue photograph, the words “no color,” “no split,” “7,” and a white–violet diagram (from top to bottom row, respectively) has to be perceived as properties of “quartz.”

The six photographs in the second row have different colors of background. The selection of background color depends on the color of each mineral. If an inscription is appropriately

structured into figure and ground, the background highlights the object in the foreground (Poizzer & Roth, 2003). For this table to take us to the identification of minerals, the foregrounds (minerals) have to be distinguished from (back-) ground, and then have to be compared to each other in the series of photographs (st5). Comparing the six photographs reveals that the table gives independent properties (e.g., appearances) of six minerals, rather than gradual variations between properties (st5). The six diagrams share the same color of background. Perceptual structuring of these six diagrams has to be focused on comparing the six figures (e.g., crystal forms) to each other. This comparison reveals that the six diagrams have different (independent) shapes and colors (st4). In addition, each diagram has a white gradient on its foreground, which has to be perceived as the reflection of light on the surface of a three-dimensional crystal (st4). Similar column-to-column comparisons have to be done with the other rows (st1 to st3). In the “color” row we can read “no color”, “white”, “black”, “green-brown”, “green-black”, and “yellow-green” in each one of the six columns, from left to right. In the “split type” (second) row the text in each column reads “no split”, “two directional”, “one directional”, “two directional”, “two directional”, and “irregular.” It has to be concluded that there are no apparent linearity or regularities in the rows of “color”, “split type” and “hardness.”

Identifying six minerals requires the comparison between rows, through between-inscription-type comparisons. The perceptual structuring of the six photographs is assisted by comparing them with the six diagrams. The six diagrams have to be seen as the reductions or the simplifications of the photographs (tl5). Comparing the photograph-diagram pairs on each column reveals that such transformation processes used filtering (in feldspar, one unit of crystal is extracted on the diagram from a number of crystals in the photograph), uniforming (in hornblende, the texture of the surface of the photograph is evened out), and upgrading (in pyroxene, the borders of the crystal are cleared in the diagram). All of these actions constitute work that went into the preparation of inscriptions (Lynch, 1990), and now requires work to move in the reverse direction.

In addition, the translations (comparisons) between photographs and diagrams and the “color” row have to be done. The “color” row has to be articulated as presenting the colors of the rock-forming minerals (crystals), instead of the colors of the background (tl2). Although comparing the color of a given figure and the word depicting that color seems to be an automatic process, in some cases, this might arise confusions; does quartz have no color? Is feldspar black? In feldspar, the color of the crystal in the diagram is uniformly black, while the color of the feldspar in the photograph is a mixture of black, yellow, and white. If the term “no color” means transparency, then the color of the quartz crystal in the photograph or the diagram should be the same color as its background. However, the color of the quartz in the photograph is white and violet, whereas the color of the background in the photograph is blue. In order to solve this puzzle, readers have to understand how the photographs were made. Readers have to assume that the photograph of the quartz was taken, for example, in a background with violet and white light, and then, later, the crystal was moved and placed against a blue background. In the case of the feldspar, the yellow-white color has to be seen as a refraction of light (st6).

Finally, the systematical comparisons are required of the relationships between split type or hardness and the shape of the mineral (crystal): Is there regularity between them? Perceptual structuring and translation reveal that there is no apparent dependency between the split type and the shape of the mineral, no possible mathematical or logical relationship between the numbers of hardness and the other properties (tl2, tl4, tl5).

In sum, the table in Figure 8 has to be structured with its columns and rows, has to be compared with photographs, diagrams, and words (numbers), in and between columns and rows. Each row and column have to be translated into the reader’s real world experiences on the properties and observations of real rock-forming minerals (tl1, tl3, and tl6).

Explanatory layer

The most frequent type of layered inscriptions in both Korean and North American textbooks is feature of explanatory layer. The lesson to be learned in reading the layered inscription in

Figure 9 is the vector addition of forces in the same direction. The photograph on the left presents a two-headed train, with two arrows of different colors just above it, with letters and numbers above each arrow. The figure at right presents several parallel arrows, again with letters and numbers above each arrow, and the equation " $F = F_1 + F_2$." Figure 10 shows the work of reading Figure 9 required for arriving at the targeted lesson. The different layers are designed to provide readers with resources to bridge the gap between their experienced world (far right in Figure 10), more easily associated with the photograph of the train, and the mathematical equation (next far left in Figure 10), the inscription farthest removed from lived experience in the world.

Initial perceptual work is required to separate different types of inscriptions: That is, photograph, arrows in photograph, diagram of arrows, and mathematical equation in diagram. Then the works of structuring, transposing, and translating have to be done. The (static) photograph must be perceived as depicting a train with two head cars moving ahead, from left to right (st8 [Figure 10]). Although in some cases the train moves backward, such cases have to be disregarded (tl11, st9). In addition, the two head cars have to be articulated as together exerting forces in same direction to drive the whole train (st8). There are special elements (another inscriptions) other than the photographic image that were added after the photograph was developed: The two arrows with letters and numbers above them. The two arrows have to be perceived as being parallel to the train, pointing to the same direction (left to right) (st6, st7). The short blue arrow has to be structured as corresponding to both the second (left) head car and to the letter and number combination " F_1 " (tl10, st6). The long green arrow corresponds to both the first (right) head car and to " F_2 " (tl10, st7). However, the caption does not state directly what these annotations mean (st9). Instead, the main text states, "Thus, when there are forces with the same direction, the resultant force (F) is equal to the sum of one force (F_1) and another force (F_2). The direction of the resultant force is the same as the direction of the two forces that are added up." With this text, the letter-number combinations can be translated into forces, and each arrow can be linked to the force of each head car (tl3). In addition, two arrows have to be

articulated as representing the directions of each force (e.g., head car), and the different lengths of the two arrows have to be inferred as representing the different magnitudes of each force, although the latter is not mentioned anywhere (tl10, st6, st7).

Fig 21 Addition of forces in the same direction. The resultant force (F) equals the sum of F_1 and F_2 .

Figure 9. Example of explanative layered inscriptions. (From Lee, Chae et al., 2000, p.231, reprinted with permission. The English translation of the caption is ours.)

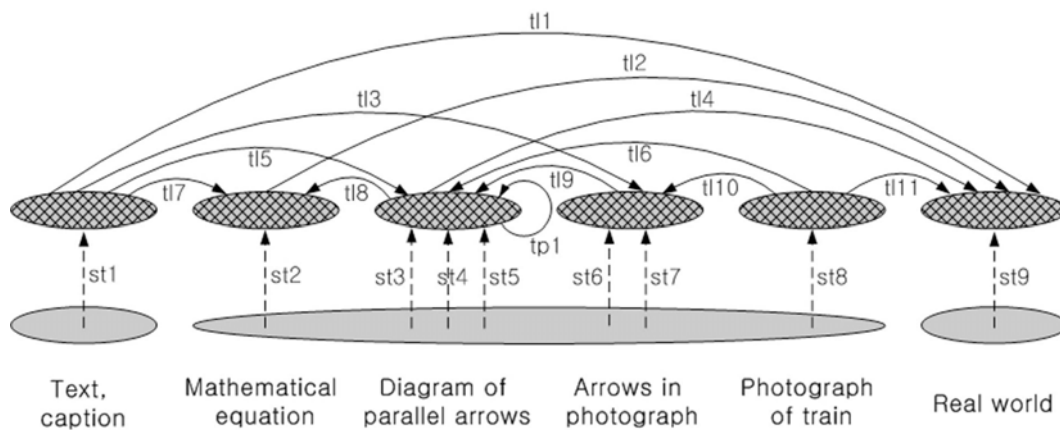


Figure 10. Works required for reading the layered inscriptions in Figure 9. Each arrow represents the work of structuring ([st], dotted arrows), transposing ([tp], circular arrows), or translating ([tl], curved line arrows).

The right diagram of parallel arrows requires complex structuring and transposing. The background of the diagram has to be seen as a graph paper (st3 to st5). The lines and arrows of the diagram are drawn onto the lines of the graph paper, providing us with the criterion for comparing the different arrows: All arrows have different lengths but the same direction (st3 to st5). The black vertical line with three “zeros” vertically aligned beside it must be perceived as ordinate of the graph (st3 to st5). Also, the tails of the arrows are all aligned with this line, parallel to each other, like the starting line where the sprinters are sitting on in a race. In addition, each arrow has letters and numbers above them, except for the red arrow in the bottom of that diagram, which presents the equation “ $F = F_1 + F_2$ ” below it. In the third row of the diagram, the

green arrow starts from the tip of the blue arrow. There is another vertical dotted line that is parallel to the black vertical line, from the tip of the top blue arrow to the middle of the bottom red arrow (st3 to st5). Comparing the color and length of the blue and green arrows reveals that the two blue arrows on the first and the third rows of the diagram represent the same entity (same length and direction), but with different locations (tp1). Thus, the first arrow is actually the third (blue) arrow, just placed in a different location on the diagram. Similarly, the two green arrows have to be articulated as being the same entity (tp1). Comparing the length of the red arrow and the two arrows in third row reveals that the red arrow has the same direction of the blue and green arrows, and the length of the red arrow is equal to the sum of the lengths of the blue and the green arrows, which are summed graphically in the third row of the diagram (tp1).

Finally, the equation, here the end-point and most generalizable aspect of a long cascade of inscriptions (Latour, 1999), has to be structured as it makes equivalent “ F ” with “ $F_1 + F_2$ ” (st2). This equation has to be articulated as corresponding to the red arrow, which is the sum of the blue and green arrows (tl8). However, the graph paper is an arbitrary space (Bastide, 1990), that is, it has nothing realistic about it. Therefore, translating is required from all the arrows in the diagram (and the equation) to the photograph (near real world) and caption or main text, for Figure 9 to lead us to the targeted lesson.

The blue and green arrows in the diagram and the photograph have to be articulated as referring the same entity, although the colors of the letters and the (green) arrows are a little different (tl5). The arrows in the photograph have to be perceived as being same arrows in the diagram, therefore with the same length and direction, and most importantly, representing the driving forces of the two head cars (tl6, tl9, and tl10). The color and the relative length of the arrows are linking cues that interrelate the photograph and the diagram. However, the direction of movement of the train in the photograph and the directions of the arrows in the diagram are not exactly the same. The train lies from left high to right low in the space of the rectangular photograph. With classical conventions of painting (and photography as well), “high versus low” is coupled with “far versus near.” Thus, the train might be seen as moving from left to right and

also from far to near (in relation to a point located outside the photograph, in this case, the reader). Readers have to ignore this little difference of direction between the photograph and the diagram (tl10). Nevertheless, the photograph gives the readers an everyday (authentic) example of forces with the same direction. The diagram depicting the resultant force has to be translated to the readers' real world experiences via photograph with the same kind of arrows on it (tl4). In this way, readers have to conclude that forces with the same direction (text and caption) can be added not only in a graphic form (diagram or photograph) (tl5) or a mathematical form (equation) (tl7), but also in a real situation (real world experience) (tl1). In addition, the lesson with this layered inscriptions will show that the arrows depicting forces that are arranged in a horizontal line along the train in the photograph can be re-arranged on the diagram vertically, in parallel, and can be is back-arranged into one line (st3 to st5).

Discussion & Implications

In the past, scholars of many disciplines—including philosophy, cognitive science, and artificial intelligence—thought about the relationship between language and world in terms of two different arbitrarily related domains. Recent work among scientists showed, however, that scientific research translates world into language by translating and structuring matter along a chain of inscriptions separated by ontological gaps (Latour, 1999). In reading a scientific text with inscriptions, readers are asked to take the inverse journey, moving from language and experience-distant inscriptions to the world. Layered inscriptions provide reading resources that break the larger gap into many smaller ones. Our semantic model captures the ordering of inscriptions and the different kinds and amounts of work required for differentiating and relating the different layers to one another and to the lived experience of the reader. This study was designed to understand the work required to learn from inscriptions, in particular, composite inscriptions, in which multiple types of inscriptions were layered on top of one another.

We identified 11 kinds of functional relationships between inscriptions layered together in Korean and North American textbooks. Except simple layered inscriptions, layering provides the

basis from which new meanings or relations emerge in and between inscriptions. How do different kinds of layers mediate reading, and thereby assist rather than hinder students in bridging generalizable cultural knowledge to personal experiences?

Our analyses provide examples of the three kinds of work required for the intended learning outcomes: Structuring and transposing within a layer, and translating between layers and between inscription and the lived experience of the reader. The additional layers of inscriptions break the overall gap between the most experience-distant inscription and lived experience into smaller gaps. However, the gaps do not disappear and continue to require work. The proliferation of arrows in our model shows that the additional layers require additional structuring, transposing, and translating work. We should therefore not be surprised when students find difficult to read and interpret these layered inscriptions, even though they were designed to facilitate learning.

Our analyses show that structuring and translating work is always required. Transposing work is required only when there are two or more inscriptions of the same kind to be compared with one other (e.g., Figures 3 and 9). With layered inscriptions, not as a single inscription, we focus on the translating work. Translating work depends on the functional relation between inscriptions. Here, the four examples analyzed exhibit differences. When a background layer is used, the work of translating takes the form of zooming (magnifying) and locating (or imagining) other inscriptions in a specific context; with an analogical layer, the corresponding work consists of active construction of analogies; comparing and filtering constitute the brunt of the work when the additional layer presents data; and some pictorial form of everyday example or experience is used in an explanatory layer. Thus, different kind of layered inscription requires different kind and amount of work. In addition, the translating works add new meaning (for example, provide context of inscription in background layer) that is impossible if there was no layer.

Layered inscriptions have the pedagogical potential to assist students in learning about a new topic. In particular, the different layers decrease the length of the steps that have to be taken from the most experience-distant inscription to the lived world of the reader. They give additional

resources to readers such as, for example, the context of an inscription, analogical material, everyday example, and scientific phenomena. However, at the same time, they require more steps to be taken, which may complicate learning. Our analyses showed the tremendous amount of work required unpacking an inscription. Our model of reading layered inscriptions articulates the different type and amount of work involved in reading such inscriptions and arriving at some new understanding.

Our work allows us to ask new questions. For example, what are the types of inscription that facilitate versus impede reading? Would alternative layers in our examples have provided advantages? For example, in Figure 1, is the work greater or less if the photograph of syringe and piston were used rather than the drawing of beaker and piston? A photograph requires structuring and translating similar to the drawing, but it is closer to real world experiences and thereby might allow students to bridge the first gap more easily. New studies, in which students are asked to read layered inscriptions, are required for determining the difficulties associated with each type of work so that the different arrows can be associated with difficulty levels. Our model lends itself to preparing experimental studies in which the different types of work are systematically varied.

Our model allows textbook authors to identify the different types of work required for the reading to unpack the lesson embodied in an inscription. Authors should consider not only all of this work in trying to make layered inscriptions, but also they should consider the related social conventions or prerequisites (experiences) that are required. Authors need to be aware that not a single aspect of an inscription can be taken as self-evident but that it requires work to unpack the lesson it contains. Sufficient resources should be provided with each layered inscriptions, such as guiding (linking) lines, arrows, and specific colors, and providing detailed explanations in the caption and in the main text. Some aspects of this work may be more difficult than others. That is, our model guides teachers in identifying the various kinds of work involved in reading layered inscriptions.

The analysis of the works required to read specific layered inscriptions can help teachers arranging those works in their lessons, helping students' learning. For example, teacher can list three kinds of works to be done, and guide students perform those works focusing on some important or difficult ones. Alternatively, the sequence of works can be used as a mean to facilitate students' discourse around layered inscriptions, fostering active participation on reading them together. Or, teacher should provide students with real world experiences that are related and required in reading inscriptions.

Acknowledgement

This work was supported, in part, by a postdoctoral fellowship from the Korea Science and Engineering Foundation (KOSEF) and by a grant from the Social Sciences and Humanities Research Council of Canada.

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