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Because this report contains a number of images from textbooks, some images are original reproductions inspired by source material and others have been removed from this version but maintained in the final form version published by Taylor and Francis.

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Running Head: ADAPTATIONS AND CONTINUITIES

Adaptations and Continuities in the Use and Design of Visual Representations in US Middle School Science Textbooks

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Abstract

Visual representations are ubiquitous in modern-day science textbooks and, have in recent years, become an object of criticism and scrutiny. This article examines the extent to which changes in representations in textbooks published in the United States over the past six decades have invited those critiques. Drawing from a correlational analysis of a corpus of 34 US middle school physical science textbooks, continuities are established with respect the purposes that most textbook images serve and the numbers of schematic representations that are used. Changes are observed in the overall total number of representations in textbooks and in the proportion of representations that are photographic. Individual, interpretive cases of representations over time are presented to further illustrate the continuities and changes that have taken place. Specifically, high-fidelity images, such as photographs, are shown permeating or replacing schematic and explanatory images in the interest of promoting familiarization to students. This shifting emphasis toward familiarization is discussed as a specific cause for concern about quality and utility of representations in modern-day US science textbooks.

Adaptations and Continuities in the Use and Design of Visual Representations in Middle School Science Textbooks

It has been both well established and long appreciated that visual representations, in the form of diagrams, illustrations, drawings, and photographs, play instrumental roles in the knowing and learning of scientific ideas (e.g., Latour, 1987; Lynch & Woolgar, 1990; Macdonald-Ross, 1979). It comes as little surprise that such representations have become one of the most pervasive and visible elements of the modern-day science textbook. The inclusion of visual representations is undoubtedly attributable to their potential to provide a support for the learning of unfamiliar scientific ideas when they are properly designed, integrated, and used by students and teachers (Cook, 2006; Mayer, 2001). Yet, even though the potential benefits of them have been generally recognized and lauded, the recent decades have been also met with many serious reservations regarding why textbooks have so many visual representations (Holliday, 1985). Woodward, for instance, has been one vocal critic in his characterization of modern day textbook illustrations being relatively unnecessary and, in newer editions, serving as more of an excess (Woodward, 1992). His criticisms had been directed primarily at textbooks in social studies, though have also been extended to elementary science textbooks. Echoing similar concerns, Chall and Squire (1991) discuss the role of eye-catching visuals in the multi-billion dollar publishing industry. Specifically, large numbers of visual representations in US textbooks are described by Chall and Squire as serving primarily to help a textbook to pass 'the thumb test' – the brief examination made by a teacher or school district representative when deciding what textbook series to purchase for their classroom or district. More recently, and specific to many current editions of science textbooks, cautions had been raised about the abundance of visual representations, as they are considered a likely source of confusion for students (e.g., Linn & Hsi, 2000 p. 115).

It would appear then that while an appreciation of visual representations in science textbooks has long been maintained, some developments over recent years have invited a great deal of critical commentary about representations in textbooks (Kress & van Leeuwen, 1996). The emergent sense from many science education scholars is that the plethora of representations in today's textbooks is problematic and perhaps even counterproductive to the learning of scientific ideas (e.g., Barrow, 1990; Cho, Kahle, & Nordland, 1985; Kikas, 1998; Stern & Roseman, 2004). The aim of this article is to examine why that perception has emerged. By way of analysis of representations that have appeared in a corpus of textbooks published in the United States across a span of roughly sixty years, the nature of the use and design of visual representations in textbooks are critically examined and discussed.

Visual representations in textbooks: A brief review

Textbooks are among the most graphically populated print materials used for the communication and sharing of scientific ideas. Some researchers have found that nearly half of the page space in a textbook is dedicated to illustration (Mayer, Steinhoff, Bower, & Mars, 1993), and that up to 85% of those illustrations in a given science textbook lack a clear articulation of content relevance (Mayer, 1993). More concentrated analysis by Roth, Bowen, & McGinn (1999) reveals the majority of representations in biology textbooks tend to be iconic pictures and images (ones that directly resemble the objects being depicted) rather than more abstract or data-centered ones that professional scientists use (e.g., graphs, data plots). Roth et al. note also that on the relatively few occasions when more abstract or data-centered representations were used, they took the form of Cartesian graphs that depicted idealized and simplified patterns far removed from their professional analogs. In a separate study, Pozzer & Roth (2003) again observed that the heavy use of iconic representations were favored by textbook authors over more data driven or technical representations. Specifically, they found that photographs were by far the most frequently encountered textbook representation (over 70% of all representations in their sample of North American high school science textbooks). Given that work, further studies into how textbook photographs are used in textbooks have been conducted (Pozzer & Roth, 2004; Sullivan, 2008). Some of that photograph-oriented research has shown that even when there is a content emphasis in the use of photographs, many science textbook photographs still fall short in depicting contexts that are most familiar to large groups of students (Sullivan, 2008). These observations complement existing reports and critiques on the utility of the representations that are ultimately published in textbooks (Chall & Squire, 1991; Woodward, 1992; Woodward & Nagel, 1987-1988), how those representations are sequenced (Nathan, Long, & Alibali, 2002), and the degree to which many representations used for exposition lack alignment with those used for assessment (Stieff, 2005).

In addition to a seeming overabundance and lack of alignment to actual scientific practice, accuracy of representations in modern day textbooks has also been raised as a serious concern. The American Association for the Advancement of Science noted a number of inaccuracies in diagrams and illustrations used in middle school science textbooks (American Association for the Advancement of Science, 2002), as have other evaluators of science textbooks (Hubisz, 2003; Iona, 1987). In fact, problems with representational accuracy have become so common that many professional and practitioner journals even maintain recurring sections where such errors are identified (e.g., Wampler, 2002). These documented inaccuracies in textbook representations are a cause for alarm, as textbooks are often treated in classrooms as authoritative repositories of knowledge. Inaccuracies are also a serious concern because representation interpretation is known to be a non-trivial activity for students (e.g., Colin, Chauvet, & Viennot, 2002; Pinto & Ametler, 2002; Stylianidou, Ormerod, & Ogborn, 2002). Unnecessary detail or slightly confusing components of a textbook illustration can steer students in the wrong direction (Mayer, 2001). Some have even suggested that many textbook representations, and the interpretations that are potentially made from them, are the source of some of the students' misconceptions we see so frequently in the research literature; Kesidou & Roseman (2002) note that visual representations in textbooks are possible causes of well-known student misconceptions and a cause for interpretive difficulty, as do de Posada (1999), Carvalho, Silva, & Clement (2007), and Colin, Chauvet, & Viennot (2002).

In sum, when one considers the varieties of representations in the modern day science textbook, there appear to be more iconic images than abstracted ones, and a number of erroneous depictions of both scientific ideas and phenomena. Given this present state, I consider in this article whether the observed tendencies of modern day science textbook representations speak to an actual historical shift or are instead a modern-day commentary on what have already been established patterns in science textbook design. It may be that textbook illustrations are simply exhibiting continuities with what has appeared before, and the research community is only now taking notice.

Conceptual Frameworks

This paper involves examination of representational change in textbooks at two levels. The first level is a macro-level view that takes whole chapters out of textbooks as a unit of analysis. As a repository of representations, I present three analyses that speak to quantifiable change in representation use across chapters from 32 different textbooks published from 1943 to 2005. In the first of these numerical analyses, the contents of the textbook are considered from a multimedia learning perspective (Mayer, 2001; Schnotz, 2002) – that is, the primary semiotic devices are either text or images. Historical trends in the use of expository text and the use of graphical figures are identified and discussed. The second quantitative analysis adopts a framework derived from Hegarty, Carpenter, & Just's work (1990) in categorizing scientific representations. Specifically, the use of iconic versus schematic representations (Hegarty, Carpenter, & Just, 1990) is compared in order to see if the high level of iconicity in modern-day texts is in fact a recent development. Finally, a third, data-driven analysis of instructional purposes is presented. In this analysis, representations are classified as serving to explain scientific ideas, to illustrate their uses in everyday contexts, or to demonstrate how one could replicate a scientific phenomenon. A comparison of the distributions of representations associated with different instructional purposes is provided. Together, these numerical reports paint a general picture of how representation use in textbooks has changed and how it has stayed the same over a span of sixty years.

The second level of analysis is more fine-grained and involves a focused look across three specific representations that appear regularly across the historical span of textbooks. It differs from the former analysis in that it addresses some more subtle aspects and changes in individual representations. For this more interpretive analysis, I consider specifically the interplay between what functional linguists call the ideational and interpersonal metafunctions of different representations (Halliday, 1985; Kress & van Leeuwen, 1996; Lemke, 1998). The ideational metafunction speaks largely to the represented content. It can be roughly characterized as the set of established ideas and semantic relationships that are being communicated through a representation. Essentially, it involves addressing what set of ideas is being represented. The interpersonal metafunction speaks to a different dimension of a representation – namely, how socially connected or distant the reader is to feel toward the scientific ideas being represented. The degree to which a representation serves each metafunction can be inferred based on the specific elements that are included in a given image against a base of disciplinary and cultural knowledge. For example, inclusion of specific graphic objects and elements that are conventionally used to communicate scientific ideas (such as the force vectors on a free-body diagram) can be used to infer the ideational, scientific meanings of the representation as they relate to Newtonian physics. (i.e., It is possible to infer what scientific principles and processes are being discussed.) On the other hand, a representation's inclusion of people or whimsical elements (such as decorative shapes) provide evidence for how someone is supposed to relate to the representation as involving familiar contexts or serving as a form of entertainment.

This emphasis on ideational and interpersonal metafunctions provides an appropriate frame for analysis for two reasons. First, as many modern day representations in science textbooks are being seen as excessive or favoring whimsy over content (e.g., Linn & Hsi, 2000), consideration of the ideational and interpersonal dimensions will enable focused discussion of whether or not the criticisms of modern day textbook images hold true. We should be able to see if there are inaccuracies being communicated and if images are serving social functions rather than instructional ones. Secondly, this frame is useful because the textbook corpus is historical in nature. Over the last half-century, some paradigmatic shifts were taking place with respect to science education in the United States along both ideational and interpersonal dimensions. Specifically, there has long been a tension in how best to communicate science to students

(DeBoer, 1991; Rudolph, 2002). Science curriculum reform in the United States has moved from what education historians have called the highly personalized 'life-adjustment' curriculum of the 1940s and early 1950s (DeBoer, 1991; Rudolph, 2002), to a disciplinarily focused and scientists driven reform effort (through the National Science Foundation's support of the Biological Sciences Curriculum Study and Physical Science Study Committee), back to a 'new progressivism' that again foregrounded students and their personal experiences (Ravitch, 1983). The movement between these paradigms should roughly correspond with a shift in the degree to which representations serve ideational and interpersonal metafunctions. If so, then we would have some concrete evidence that national policies regarding science education have actual manifestations in the commercialized images of science that are ultimately published and distributed.

Hypotheses

Below I offer three hypotheses, informed by the above discussion of modern-day textbook representations, documented changes in the recent history of US science education reform, and on many informal conversations with science educators and researchers about their own best guesses for what the nature of that representation use over time in textbooks should look like and what changes should be observed. These include:

1) *An increased status of representations in science textbooks.* Representations would somehow play a more prominent role over time. Considering the limited page real estate, for representations to play the larger role, they will occupy areas that were, in the past, reserved for text. The use of text as a semiotic medium should exhibit some decline.

2) *A general decline in the use of abstract representations and a major increase in more concrete and familiar representations*. Modern-day textbooks are expected to have become increasingly iconic and more focused on illustrating applications of science than on helping students to understand the underlying ideas and principles.

3) *An overall decline in scientific accuracy over time, as the representations migrate further from explanations of scientific ideas and more toward personalization.* This change is hypothesized as one that will be fairly dramatic, given the number of concerns that have been voiced and problems that have been identified in recent decades.

Data corpus

The data corpus was comprised of the student edition of 34 commercially published science textbooks published in the United States between 1943-2005. These texts were all designated for use with middle grade students (6-9). (A listing of the textbooks collected for this study is provided in Appendix A).

A single content area in physical science, light and optics, was analysed for this study. One reason for the focus on this topic is because teaching of this topic often involves the use of standard diagrams for depicting light that correspond to the wave and particle models of the nature of light. Since producing these involved following some established conventions, variation in how representations are designed was anticipated as being easier to detect. At the middle school level, an emphasis is placed on both familiarizing students with the topic and observable phenomena related to light and some of the more elementary formalisms (e.g., light depicted as rays that follow geometric patterns) are first introduced. Because the middle grades are often the point where textbooks shift from being highly pictoral to becoming much less so

(LaSpina, 1998), this span of grade levels was considered an especially appropriate one for observing the nature of change and variation in the representational composition of science textbooks.

The textbooks for the present work were obtained from practicing and retired teachers in a major metropolitan area in the Midwestern United States, from university libraries, from retailers, from current publishing companies, and from a major curriculum repository at the national Center for Research Libraries located in Chicago, Illinois. The latter houses such an extensive collection of thousands of US textbooks that they have, to this day, not yet been fully archived and are still stored in a secured vault. Through the gracious permission of the managing librarians, I was able to spend several days browsing the sealed collection in order to obtain texts published during the selected time period for this study.

Representativeness of the textbooks was determined based on three considerations: the name and reputation of the publisher, if the text was included in other studies that considered them to be representative, and personal recommendations from informants who, by virtue of their professional positions, were knowledgeable about the textbook industry in the United States. The major publishers included publishing divisions such as Holt, Rinehart, & Winston, McGraw-Hill, Pearson, Glencoe, Houghton Mifflin, Scott Foresman, and Prentice Hall and their subsidiaries[1]. Major studies that had previously identified major publishers and series that informed the sampling in this study included Kesidou & Roseman (2002) and Hubisz (2003). Informants included current and former marketing employees at publishers, practicing teachers, and managing librarians.

[1] A number of these are owned by the same media company, though had in the past been independent publishing groups that had been acquired or merged over time.

The mean number of textbook pages pertaining to light and optics included was 30.9. This did not include decorative title pages or chapter test pages, which some textbooks included and some did not. The requirement for pages to be included in this study was that the page contain at least some amount of main expository text – the main body of text that is intended to explain, describe, or otherwise present the science content. Whether or not that page contained illustrations was not considered, though nearly all pages had at least one graphic figure. Across this span of pages, the average number of graphic and visual representations was 36.4.

What counts as a visual representation?

In a quantitative analysis of textbook images, one inevitably encounters an issue of grain size. As graphic designers have become increasingly creative in their produced images, and as techniques such as layering (Han & Roth, 2006) have begun to appear, what counts as an individual visual representation in a textbook can vary widely across textbooks series. Making such a distinction as to what constitutes a single representation is a challenge noted by others who have systematically studied textbook images (e.g., Pozzer & Roth, 2003). For example, there are occasions in which an illustrative figure is simply a lone picture and others when it is multiple pictures, and others still when it is a mix of drawings and photographs that have been segmented into multiple panels. Figure 1 illustrates the variety across four textbook representations, all of which deal with image formation in with curved mirrors. Note that some include isolated drawings while others juxtapose two different images together.

[INSERT FIGURE 1 ABOUT HERE]

For the purposes of this work, a fairly inclusive approach to counting representations was adopted. Anything that had been designated by the textbook author, through statement in the main text or by a caption, as being an illustrative figure was counted as a single representation. This was the case for multipaneled representations. Therefore, in Figure 1 each of the four figures is counted as a representation. In total, the corpus contained roughly 1500 representations. By using this method of counting, the analyses I present are fairly conservative, with respect to the numbers of representations.

Quantitative Summaries of Representation Use

Word and representation counts

To determine how many words and representations were being used, average words per page for each textbook were calculated by averaging the number of main text character strings in the first five pages of expository text pertaining to light and optics. This counting of words was not inclusive of chapter titles, margin notes, or captions. Instead, this body of text was considered the main expository text that was intended to be followed as part of a linear reading progression. Average images per pages of text were determined by computing the total number of representations associated to or referenced by the analysed sections of the textbooks and averaging that against the total number of pages of expository text in which those representations were included. The ratio of average words per representation was determined by dividing the average words per page by the average number of representations per page. Plots of each of these as based on textbook publication date are provided in Figure 2.

[INSERT FIGURE 2 ABOUT HERE]

Based on computation of Pearson product coefficients and a least squares regression, the trend over time appears to be a decrease in the number of words over time and an increase in the number of images per page to increase. However, the decrease in words is not statistically significant (for words per page, $r = -0.18$, $t=1.055$, 32 df, $p > .4$). There is a significant positive correlation for the number of representations per page ($r = 0.47$, $t = 8.972$, 32df, $p < 0.01$). The number of words per page of this sample varied greatly, so it may be that a larger sample would actually reveal a significant decrease. However, based on these calculations, it would seem that the hypothesis that there are becoming increasingly more pictures is correct, though that increase is not affecting the total amount of text.

Note that these counts only consider the main expository text and referenced representations. Therefore, margin text, in the form of additional facts or queries to support reading comprehension, are not included. Those portions of margin text would be occasionally accompanied by representations, though they tended to be of a strictly decorative kind. For example, related ideas may be marked by an icon of gears working together (symbolizing the connection of the science topic to another topic) followed by a few sentences of textual description of the related idea. Because those additional callouts and sentences were excluded, the expectation would be that inclusion of such areas of text would actually further mitigate any apparent decrease in the use of text in textbooks. Instead, what appears to be happening is that more representations are being added at little to no cost of number of words used. This is likely facilitated by more economical use of space, in which text placed flush against oddly shaped representations, and through a gradual increase in page size. Modern day pages in student textbooks measure over 9 inches (22.86 cm) by 10 inches (25.40 cm). In 1979, a textbook page would measure 7.75 inches (19.69 cm) by 9.25 inches (23.50).

What types of representations are being included?

Hegarty, Carpenter, & Just (1990) have previously offered a classification of scientific representations, particularly as they are used in scientific texts. They delineated three categories of scientific representations: iconic, schematic, and charts & graphs. These are listed in order of increasing abstractness and in order of increasing potential for depicting patterns and relationships. Iconic depictions include things like photographs and line drawings of objects. Both of these kinds of iconic representations are very common in contemporary science textbooks (Pozzer & Roth, 2003; Roth, et al., 1999). Iconic representations are described by Hegarty, et al. (1990) as being used to communicate primarily spatial information about objects in a way that roughly corresponds to the spatial relationships of the referent (e.g., Figure 1d). Schematic representations are more abstract and involve abstract, concise notations to describe key relationships or interactions (e.g., Figure 1a). Diagrams of light rays interacting with matter comprise one of the numerous types of schematic and abstract representations in optical sciences (Ramadas, 1982). Other examples from other content areas would include circuit diagrams, cladograms, and free-body force diagrams. The Charts & Graphs category, in which two or more variables are systematically displayed and their relationships exposed, was minimally applicable to this analysis. As noted above, others such Roth, Bowen, and McGinn (1999) have established that such representations are rather infrequently used in commercial science textbooks.

Codes that roughly mapped onto the first two pieces of Hegarty et al's diagram classification scheme were used, though adaptations were made with respect to issues specific to the kinds of representations that appear in science textbooks. Instead of treating all iconic depictions as a single group, I instead considered what 'graphic medium' was used. By graphic medium, I basically mean whether the representation was a photograph, a line drawing (i.e., rendered freehand), or schematic and abstracted inscription (i.e., a light ray drawing). The expectation here would be that as more realistic depictions (photographs) could be more easily obtained, the need for hand-drawn approximations would decrease. This shift is considered to be an important one to examine, given the attention given recently to the ways in which photographs are used in textbooks (Pozzer & Roth, 2003; Sullivan, 2008). To illustrate the coding, sample codes are shown in Figure 1.

Note that the assignment of these codes was not mutually exclusive, as the blending of media was not at all uncommon. Also note that these codes do not directly address what would be considered the scientific content of any representation. However, they can serve as a proxy for the degree of abstractness or concreteness of a representation, relative to what is familiar to a student. They also serve as a window into an epistemic emphasis in textbooks – whether the overarching goal of the author was to train students about the depth and generalizability of scientific ideas or to familiarize them with how science is real and tangible.

In interpreting the results, I had considered the numbers of illustrations involving some technical notations (e.g., light rays, like in Figure 1a, b, and c) to be suggestive of a degree of abstractness of ideas that are represented. The numbers of photographs and line drawings were interpreted as reflecting the number of representations that, based on the fact that they depicted tangible objects or everyday situations, were already concrete. Plots of each are shown in Figure 4.

[INSERT FIGURE 4 ABOUT HERE]

There are a few points worth noting from this analysis. First, there is a great deal of variability over time. With freehand drawings, there is not an obvious pattern in their frequency.

In 2005, roughly the same number of freehand drawings were appearing as had been in 1943. In between these two endpoints is a dramatic fluctuation between having almost no freehand drawings (1979) to having almost two per page (1993). This variability undoubtedly contributes to an insignificant correlation of -0.12 ($t = -0.74$, $df = 32$, $p > 0.1$). Similarly, the use of schematic drawings, in which rays and waves are used to depict light, has also fluctuated throughout the years. Overall, though, there appear to be hints of a slight increase over time in the use of schematic representations, though the correlation there is also statistically insignificant ($r = 0.10$, $t = 0.62$, $df = 32$, $p > 0.1$). Where a genuine change appears is in the number of photographs over time, which appears to be an increase, particularly in the 1990s. ($r = 0.62$, $t = 4.51$, $df = 32$, $p < 0.05$). These results suggest that a great deal of the increase in representations is in the use in iconic representations, though that is specific to photographs. This suggests that the recent attention in the research literature to photographs (e.g., Sullivan, 2008) and how they are used in textbooks is both timely and appropriate.

Are the instructional purposes changing?

If realistic photographs are especially well-suited to showing real-world situations and those are becoming more prevalent, then is the goal of the images in textbooks shifting toward illustrating science rather than explaining it? That shift may be expected since photographs are well suited to capturing representations of the familiar and directly observable. To examine that issue, I conducted an additional analysis that examines the instructional purposes of the representations in this corpus.

From iterative reviews of the corpus and a constant comparative approach (Glaser & Strauss, 1967), I had identified and present here three classes of instructional functions that representations play in textbooks: an explanatory function, an illustrative function, and a demonstrative function. The explanatory function is associated with representations that communicate scientific principles, rules, or behaviours. They often show the mechanisms, structures, and processes that explain everyday and experimental phenomena. Often, explanatory representations include some kind of schematic or symbolic notations, as those stand for the theorized entities and relationships. Illustrative representations are involved in showing a phenomenon, but not for the purposes of providing a mechanistic explanation for how or why that phenomenon occurs. Other illustrative representations show everyday instantiations of a principle. For example, imagine that a photograph of a firetruck is shown in a textbook section describing the Doppler effect (the change in wavelength and frequency of a wave as it travels relative to an observer). The depiction of a firetruck does not explain why continuous sounds change pitch when they originate from a traveling object. The firetruck picture just shows a familiar, everyday object from which the Doppler effect can be perceived. A modeled activity for students to enact, such as having a student ride a bicycle past some observers while blowing a whistle, would be a demonstrative use. The primary goal of that depiction would be to show students how to set up a situation to produce the effect. A drawing of the actual waves themselves, with their center moving over time, would be explanatory, as it introduces a theorized entity and a mechanism to explain the effect.

Most representations in the corpus can be coded with just one of these three as a primary code, simply by examining what objects are depicted and what was the textual context. However, that there are some occasions when there is overlap in functions. Often this is due to the multipaneled structure of some representations, and a mixing of graphic media (e.g., Figure 1).

For the purposes of this analysis, my concern was whether the macro-level shifts in depictive medium was also accompanied by a macro-level shift in instructional function. For instance, more photographs would seem to lend themselves most to more illustrations of phenomena and depictions of everyday objects that are somehow topically related. They would not seem to be the kind of representational format that would typically be used to explain scientific principles. A comparison was made between the 10 textbooks that were published prior to 1971 and the 8 textbooks that were published after 1990 so as to make any contrasts visible. Seven categories of instructional functions were designated (explanatory, illustrative, demonstrative, and each possible combination of those three) and each representation was assigned to one of the seven categories. The average number of representations in each function category was computed and the results are plotted in Figure 3.

[INSERT FIGURE 3 ABOUT HERE]

From this, it appears that the distributions are roughly equal, suggesting relatively little change over time in the instructional functions that representations are serving within a textbook chapter. There is a slight increase in the number of representations that are demonstrative and in the number of representations that are simultaneously illustrative and explanatory. The difference in the number of representations that simultaneously serve both illustrative and explanatory functions between the post-1990 and pre-1971 is a significant one ($t = -2.22$, $df = 10.582$, $p < 0.05$). Many of these representations are layered, in much the same manner as described in Han & Roth (2006). This change over time change suggests that the layering depiction technique in textbooks has been an increasingly popular approach in representation design. In general, though, the overall increase in representations is coming from a general increase in representations that serve all of these different functions. Demonstratives, in the form of lab activities and apparatus illustrations appear to be increasing, though it does not appear to be a significant difference ($t = 1.09$, $df = 9.734$, $p > 0.05$). Surprisingly, the increase in photographs does not appear to be tied with major changes in the ways that visual representations function instructionally in textbooks.

Individual cases of representational change over time

Thus far, I have spoken only to the gross numerical trends in the collection of representations used in textbooks. These include an overall increase in the number of representations, specifically in photographs, and a general maintenance in the instructional purposes representations serve in the textbook. I have not yet presented instances of what, if any, changes have appeared at the level of the individual representations. From the numerical analyses above, specifically those related to instructional function, it would seem that there have been relatively few changes. To determine if that is an accurate characterization, I present three brief descriptive cases of representations from different times. Each representation corresponds with either the disciplinarily-focused textbook reform period (1957-1970) or the more student-focused period (1980-present).

My intent in presenting these cases is to illustrate some of the recent developments in textbook representation design and to consider seriously *how* science is being communicated these representations. To build these cases, I assembled and grouped all instances of the representations based on a content that was being represented and performed iterative interpretive analyses of the individual representations, noting specifically the differences in older and newer ones and how they affected how the components of the representations functioned ideationally and interpersonally (Halliday, 1985; Kress & van Leeuwen, 1996; Lemke, 1998).

Specific attention was paid to the number of graphical elements included, the meanings that are intentionally being communicated, and the ‘naturalism’ of specific graphical elements (Kress & van Leeuwen, 1996). By naturalism, I refer to how closely a represented object bore resemblance to something from the physical world. My discussion focuses on how different aspects of the representation serve the ideational and interpersonal metafunctions discussed above.

The Electromagnetic Spectrum

The first case involves the electromagnetic spectrum, a representation often used to show different categories of electromagnetic radiation and the inverse relationship between wavelength and frequency. This representation was selected for more detailed examination because it is one of the few occasions in which light is discussed in terms of a wave model (one of the two models most often used to explain the nature of light), and it is also one of the few chart-like scientific representations (Hegarty, et al., 1990) regularly used in middle school light and optics instruction.

By design, the electromagnetic spectrum representation uses horizontal positioning to communicate a fundamental mathematical relationship between wavelength and frequency and to express that there are many different types and uses of electromagnetic radiation. Depending on where one type of radiation is positioned relative to another, one can infer which has a higher frequency and which has a longer wavelength. For example, ultraviolet radiation is located to the right of infrared radiation. Because of that positioning, it can be inferred that ultraviolet radiation has a higher frequency and infrared has a longer wavelength. The communication of these ideas is a part of Figure 5’s ideational metafunction. From the representation, it is hoped a sophisticated reader can infer for any of the listed radiation types how wavelengths and frequencies differ. A reader should also be able to derive a sense of how much bandwidth of the spectrum a particular radiation type occupies. For instance, from Figure 5, it should be understood that visible light occupies a relatively small portion of the spectrum, especially in comparison something like radio waves. It is worth noting that Figure 5 is a rough approximation. If the spectrum were drawn to scale, the relative proportions would have to change. For example, visible light would be essentially reduced to a thin vertical line.

[INSERT FIGURE 5 ABOUT HERE]

With respect to the interpersonal metafunction, there is evidence in this older depiction of a limited effort to socially connect to readers. It is not plainly apparent because Figure 5 largely maintains a social distance by being both relatively sparse and lacking in any décor or images that would directly breed familiarity. However, in the textual labels for different types of radiation, there are some descriptions as to how that radiation is useful to people and society. For example, under ‘ultraviolet’ radiation, the words ‘suntan, vitamin d, radiation, germ killing’ appear. Those words all describe the ways in which ultraviolet radiation affects people or can be beneficial or harmful.

[INSERT FIGURE 6 ABOUT HERE]

In comparison, Figure 6, from a more recent textbook, places much greater visual emphasis on establishing social connections. What has become especially prominent in Figure 6 is the use of photographs to illustrate the uses of different types of radiation. With the photographs, the reader is brought closer to an understanding of how electromagnetic radiation appears in daily life and affects people. Everyday objects, actual people, and even an x-ray depicting a ‘thumbs-up’ sign are all naturalistic images included along the bottom of this representation, and their familiarity serves to put a student at ease with what they are seeing (Kress & van Leeuwen, 1996). The viewer is placed in a more socially engaged position. Those items contribute to the interpretation of this representation as more visibly serving interpersonal metafunctions. The representation makes a strong commitment to familiarizing science and associating it with everyday contexts. However, in Figure 6, this is also accompanied with a loss of information. While changes and in wavelength and frequency are still presented through the use of labeled arrows and additionally through a graphic depiction of a wave with a shrinking wavelength, information about the relative bandwidth of a radiation type is lost. Nearly all the listed types of electromagnetic radiation are associated with equally sized boxes, with the exceptions of visible light and ultraviolet radiation. The relative sizes are in no way reflective of the actual range of wavelengths that they span. Instead, the uses of different radiation types is foregrounded and serves as the organizing scheme for the spectrum. Some of the precision that was reached by the older representation is lost in the newer incarnation. In sum, the emphases on the ideational and interpersonal metafunctions has changed over time; some of the core ideas that were depicted in the earlier version are now less clearly articulated than they were before and some of the ways in which electromagnetic radiation is personally relevant become more visually pronounced.

Light Reflecting in Concave Mirrors

The second case involves light rays reflecting off of a concave mirror. As optics often involves extensive use of these kinds of light ray diagrams, this was selected as one representative case of that class of schematic drawing that is typically used in discussing the reflection of light and formation of images. The concave mirror and light representation bears a strong resemblance to other graphical depictions of light as it reflects off of convex mirrors and also as light is refracted through concave and convex lenses. In the case of reflective concave surfaces, light rays that are parallel to the axis of symmetry are reflected such that the reflected rays all travel through roughly the same point. Many textbooks illustrate this by showing an object (typically a mirror) with one inwardly curved surface and multiple light rays that reflecting against that surface. That method of depicting concave reflection and the emphasis on idealized concave surfaces has remained quite constant throughout the decades (e.g., Figure 7).

[INSERT FIGURES 7 & 8 ABOUT HERE]

What has not remained constant has been the actual graphical objects used to depict of light in that situation. These differences are illustrated when the examples from Figure 7 are compared to those in Figure 8. In those examples, both from textbooks published in the 2000's, light is depicted as having a perceptible thickness and tangibility. It is, in itself, almost a tangible object. This is a stark difference from earlier decades when light when they were rather sparse and simple looking arrows. Figure 8 illustrates how in modern textbooks, many depictions use actual photographs of laser light to demonstrate how rays behave during reflecting. When those photographs are not used, an alternative is to use thickened arrows, often coloured yellow, and drawn with faded tail ends

There are some reasons to appreciate the thickened line approach, in that it may help readers to understand that it is light that is involved is being depicted. It may also lend an air of additional realism to these behaviours given the more naturalistic appearance of the new representations. However, the new versions are also associated with a trade-off. Each of the renderings in Figure 8 potentially imbues light with properties that it does not have. From the photograph of lasers, light might be understood as something observable by naked eye and beam-like in nature. The photograph of the lasers provides evidence to a naïve reader for such an interpretation. In reality, the visibility of light beams and the beam-like nature of light can only take place under very special conditions (i.e., the Tyndall Effect). Neither of these things are mentioned in the textbook or with the images. Also, in the thick-arrow drawing from 2005, the faded tails on the lines depicting light can be taken to suggest that light intensity decreases as it travels or that more intense light can be found further from a light source. These potential misinterpretations are similar to those noted in the research conducted by Colin et al, in their interviews with students and teachers about how they comprehended optics representations (2002). In terms of the ideational, it is far less clear what the authors had intended to convey in the newer versions and how consistent those intentions are with what is accepted in the scientific community. Had the intensity of colour in the representation been intended to map directly onto the intensity of the light that is being represented, we could safely conclude that the ideas regarding light are inconsistent with accepted scientific fact.

In addition to an increase in the size of the lines that depict the reflected light, there has also been a decrease in how much light is being shown. This is perceptible by comparison of the number of lines depicting light that are used between Figure 7 and Figure 8. A t-test comparing numbers of lines in concave mirror drawings in pre-1980 textbooks an post-1980 textbooks reveals that the difference is statistically significant ($t = 3.28$, $df = 13.5$, $p < 0.01$). There are roughly twice as many light rays shown in the older texts.

The importance of this change can easily be stated primarily as another change in the ideational dimension. These changes happen to also deemphasize the fact that the reflective behaviour demonstrated apply to all parallel light rays, though depending on the angle of incidence with the mirror, the angle of reflection for each light ray will differ. A more precise articulation of this is communicated through Figure 7.

Transparency, translucency, and opaqueness

The final case of historical change in a representation involves one of the categorical distinctions about light and matter interactions. In particular, it is the distinctions made between objects that are transparent, translucent, and opaque, depending on how much, if any, light passes through them. By and large, most modern day representations related to this categorical distinction resemble the illustration in Figure 9. That is, they are photographs or drawings of everyday objects with labels designating to which category each object in a picture belongs. In Figure 9, plastic wrap is designated as transparent, wax paper is translucent, and aluminum foil is opaque. Given the vividness and familiarity of the objects, Figure 9 is clearly designed with an emphasis on the interpersonal.

That representation essentially communicates to the student where and how these distinctions can appear in the reader's everyday life, and thus makes science relevant to things that the reader already knows about. It is not intended to address nor explain how those distinctions are made beyond what students can directly perceive. Namely, a reader can see the sandwich clearly in plastic wrap, partially in the wax paper, and not at all in the aluminum foil. The role light plays is unclear.

[INSERT FIGURES 9 & 10 ABOUT HERE]

Figure 10, published in 1958, takes a very different approach and is an effort to show light travelling to and through three objects made up of materials that are transparent, translucent, or opaque. The three larger arrows coming from the top are incoming light and only with the transparent material do the those three lines continue on the other side. For the translucent and opaque materials, absorption of light is represented by a number of squiggly arrows inside of the container. Some smaller arrows leave the bottom of the translucent material to depict light that does travel through the object, albeit at very different angles than it had entered. Across all three representations, there is also some light that is shown as reflecting off of the top surface of each object. The intent here is to communicate that even with a transparent material, not all light is transmitted. Some light is reflected in order for the transparent object to even be seen. These additions reflect greater attention to communicating details of the many interactions of light with the different materials, and therefore indicate a stronger ideational emphasis relevant to the science content.

Note though that Figure 10 is far from perfect. First, it may attempt to convey more content than is necessary for the target audience. It is unclear whether middle grades students need to know that light can be converted into kinetic energy upon absorption for them to appreciate how light and materials interact. There are also some problems of accuracy in Figure 10 as well. For instance, there appear to be the same number of squiggly arrows in the opaque material as in the translucent one, and this might inappropriately imply that the two materials absorb the same amount of light. That may in turn make Figure 9 a more desirable one to use for modern-day instruction, as it is more accurate in its depiction of how transparent, translucent, and opaque objects differ. But, as stated above, it communicates a very different set of ideas because it simply makes the categorical distinction and does not attempt to explain the sequence of events related to light transmission and absorption.

Conclusion

Has the design and use of representations changed over the past six decades in the United States, and if so, how? In discussing the results, I will return to and discuss the earlier stated hypotheses about how representation use and design has changed in science textbooks.

First, an overall increase in the status of representations was expected. Images were predicted as becoming more numerous over time, and were expected to gradually be taking the place of text. From the quantitative analyses, we have seen that there has indeed been an increase in the total number of representations that are being included within textbooks, with the greatest increase coming from a more aggressive use of photographs. In total, we are seeing nearly twice as many representations per page now than we were half a century ago. The overall increase in visual representations is not coming at the expense of text, but rather the increase is occurring while the same amount of written text is being maintained.

Second, a general decrease in representations that were more abstract or schematic was hypothesized. Representations were expected to become increasingly iconic. The findings here are a bit nuanced. The overall increase in photographs suggests that there must be more movement toward iconicity and concreteness, as photographs are among the most vivid print representations we have at our disposal. Yet, the number of occasions in which schematic or abstracted representations appear does not exhibit a clear historical trend. In general, it appears that the frequency of use of such schematic representations has long been variable and continues to remain so. Some textbooks use schematic representations a lot and some use them relatively little. Given that, it may be most appropriate to suggest instead that for *some* textbooks, a relative decrease in the use of abstract and schematic representations could instead be taking place. An absolute change in numbers does not appear to be taking place.

Also hypothesized was an increase in the use of representations to illustrate applications science rather than explanations of it. From counts of the instructional functions associated with representations, this does not appear to be the case when chapters of textbooks are looked at as a whole. Overall, the distributions of explanatory, illustrative, and demonstrative representations have not significantly changed. Interestingly, the average number of illustrative representations is nearly double that of those that are explanatory in any given textbook. What this suggests is that, while today there are many occasions modern textbooks that use images primarily to illustrate science, many older textbooks have themselves set that as precedent. Modern day critiques of what appear to be extraneous representations are more appropriately seen as critiques on the whole genre of textbooks as it has existed for decades. As a side note, the fact that these distributions have not changed in spite of the overall increase in representations suggests that textbooks are still being called upon to serve the same instructional functions as they have for the past sixty years. Perhaps this is because the varied stakeholders involved in guiding science education policy have not yet set unified expectations or guidelines for how representations should be used in science textbooks.

If that conjecture is valid, then in the absence of a coherent set of guidelines, the development of textbooks has been indeed been simply left to the forces of the market (Chall & Squire, 1991) and publisher's intuitions about how graphics can best support students (LaSpina, 1998). As science education reform in the US has moved toward and then away from disciplinary rigor, individual representations were pushed by those other factors to become something new. The changes that resulted speak to the last hypothesis, regarding the loss of scientific accuracy. When the modern-day and older representations are compared, the emphasis for the modern day ones has been on making social connections to readers. In the examples that I have shown here, which are representative of the larger corpus, this interpersonal emphasis might have some effect on accuracy, but the more substantive change appears to be a decrease in precision. Many details that were included or attempted in the past are not being treated in the present. As a result, individual representations are exhibiting a qualitative shift, and the greater emphasis appears to be toward the interpersonal. This shift, in addition to the increased overall abundance of images in textbooks, has enabled critiques to be made in recent decades.

There is no obvious reason why a commitment to precision and a commitment to personal familiarity to science must be at odds with one another. Yet in many commercial textbooks, the two commitments have not been simultaneously honored. The most recent emphasis has tended to be on depicting that which is most familiar to students, and on occasion, that has come at the expense of communicating details of the science content.

Study limitations

In closing, I would like to acknowledge some of the limitations associated with the study. First and foremost, this is a study of textbook pages dealing with one content area and targeted at one grade level. It could certainly be that other content areas or other grade levels would exhibit either greater uniformity or greater change. Second, the manner in which the counts were done could also be limited. Before I had discussed how representations were counted very conservatively; anything that was designated by the textbook authors as a figure or illustration, even if it was multipaneled, was considered as a single representation. While an overall increase in representations was noted, it could be that the increase is much more dramatic than what is shown here because of the conservative approach to counting. If that were the case, then there would indeed be dramatic changes at the level of the textbook chapter that are not being detected here. However, developing something like a fully standardized way to count representations is ultimately a very difficult endeavor. This is largely because the ways in which multiple representations can now be seamlessly integrated with one another. These challenges are similar to those involved in studies of multimodality (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001), as the boundaries of representations in actual instructional artifacts or activities are notably difficult to tease apart.

Additionally, the analyses presented here were narrowed in scope to focus strictly on representations. While the amount of text was counted, the actual content of the text was not evaluated. This could bear on some issues related to how a reader actually might be inclined to interpret a representation and how serious any problems of accuracy may be. A well-written textbook might advise readers to only attend to specific features of representations and thus prevent them from learning incorrect ideas. Moreover, the textbook itself is only one ingredient in science education practice. The extent to which these representations have an influence in actual instructional practice is unclear, as the manner in which textbooks and representations are used can vary dramatically across classrooms. Other print materials, such as teacher's guides, workbooks, and lab manuals also play major roles. Those often are bundled with commercial textbooks, and they were not analysed here.

Still, the discussion provided here about how textbooks use of representations and representations themselves have changed provides one glimpse into recent historical times, and helps to make the case that larger scale science education reform paradigms characteristic of a country at certain periods in history can and do correspond to some degree with the visual representation of scientific ideas, at least at the micro-level. It also illustrates how the textbook as an archive of representations can still stay fairly stable, despite those micro-level changes. Future empirical work should seek to further validate or challenge these observations.

Appendix A

Middle grade (6-9) science textbooks published in the United States that were collected and analysed for this study:

Aldridge, B., Aiuto, R., Ballinger, J., Barefoot, A., Crow, L., Feather, R., et al. (1998). *Science Interactions Course 1*. New York: Glencoe/McGraw-Hill.
Alexander, P., Feigel, M., Foehr, S. K., Harris, A. F., Krajkovich, J. G., May, K. W., et al. (1988). *Physical Science*. Morriston, NJ: Silver, Burdett & Ginn.
Atwater, M., Baptiste, P., Daniel, L., Hackett, J., Moyer, R., Takemoto, C., et al. (1995). *Macmillan/McGraw-Hill Science*. New York: Macmillan/McGraw-Hill.
Blanc, S. S., Fischler, A. S., & Gargner, O. (1963). *Modern Science 2*. New York: Holt, Rinehart, & Winston.
Beauchamp, W. L., Mayfield, J. C., & West, J. Y. (1958). *Science Problems 3*. Chicago, IL: Scott Foresman.
Beauchamp, W. L., Mayfield, J. C., & Hurd, P. D. (1964). *Science Problems 3*. Chicago, IL: Scott Foresman.
Bogford, C., Champagne, A., Cuevas, M., Dumas, L., Lamb, W. G., & Vonderbrink, S. A. (2004). *Holt Science & Technology: Physical Science*. Austin, TX: Holt, Rinehart & Winston.
Brandwein, P. F., Beck, A. D., Hollingworth, L. G., & Burgess, A. E. (1955). *You and Science: Science for Better Living*. New York: Harcourt Brace.
Brooks, W. O., & Tracy, G. R. (1952). *Modern Physical Science*. New York: Holt.
Brooks, W. O., Tracy, G. R., Tropp, H. E., & Friedl, A. E. (1966). *Modern Physical Science*. New York: Holt.
Brown, W. R., & Anderson, N. D. (1972). *Physical Science: A Search for Understanding*. Philadelphia, PA: Lippincott.
Carpenter, H. A., Bailey, G. A., Smith, P. E., & Tuttle, M. E. (1943). *Advenures in Science with Ruth and Jim 6*: Allyn & Beacon.
Carter, J. L., Bajema, P. M., Heck, R. W., & Lucero, P. L. (1971). *Physical Science: A Problem Solving Approach*. Boston, MA: Ginn.
Cooney, T. M., Pasachoff, J. M., & Pasachoff, N. (1990). *Physical Science*. Glenview, IL: Scott Foresman.
Craig, G. S., & Lewis, J. E. (1950). *Going Forward with Science*: Ginn & Company.
Cunningham, J. D., Gardner, R., & Troost, C. J. (1975). *Modular Activities Program in Science*. Boston, MA: Houghton Mifflin.
Davis, I. C., Burnett, J., Gross, E. W., & Johnson, T. D. (1962). *Science: Observation and Experiment 1*. New York: Holt, Rinehart, & Winston.
Grasso, P., & Chant, A. E. (1987). *Science: Life, Health, Earth, Physical (Level F)*. Cleveland, OH: Modern Curriculum Press.
Harcourt, Brace, & Jovanovich (1989). *General Science*: Harcourt, Brace, & Jovanovich. New York.
Heimler, C. H., & Neal, C. D. (1979). *Principles of Science*. Columbus, OH: Charles E. Merrill Publishing Co.

Hurd, D., Johnson, S. M., Matthias, G. F., McLaughlin, C. W., Snyder, E. B., & Wright, J. D. (1986). *General Science: A Voyage of Exploration*. Englewood Cliffs, New Jersey: Prentice Hall.

McDougal Littell. (2005). *Waves, Sound, and Light*. Evanston, IL: McDougal Littel.

Morrison, E. S., Moore, A., Armour, N., Hammond, A., Hayson, J., Nicoll, E., et al. (1993). *Science Plus: Technology and Society*. Austin, TX: Holt, Rinehart, & Winston.

National Geographic Education Division, McLaighlin, C. W., Thompson, M., & Zike, D. (2005). *Physical Science*. New York, New York: Glencoe/McGraw-Hill.

Nolan, L. M., & Tucker, W. (1985). *Heath Physical Science*. Lexington, MA: D.C. Heath & Company.

Oxenhorn, J. M. (1970). *Pathways in Science 3*. New York: Globe Book Company.

Painter, D. H., & Skewes, G. J. (1950). *General Science*. Chicago: Mentzer Bush and Company.

Parker, B. M. (1960). *Light*. Evanston, IL: Row, Peterson, and Co.

Prentice Hall. (1989). *General Science, A Voyage of Exploration*: Prentice Hall. New York.

Ramsey, W. L., Gabriel, L. A., McGuirk, J. F., Phillips, C. R., & Watenpaugh, F. M. (1986). *Holt Science*. New York: Holt, Rinehart, & Winston.

Smith, R. G., Ballinger, J. T., & Thompson, M. (1993). *Merrill Physical Science*: Glencoe/MacMillan.

Thurber, W. A., & Kilburn, R. E. (1966). *Exploring Science Seven*: Allyn & Beacon.

Williams, G. A., Bolen, M. C., & Doerhoff, R. B. (1973). *Challenges to Science: Physical Science*. Chicago, IL: McGraw Hill.

References

American Association for the Advancement of Science (2002). Middle Grade Science Textbooks: A benchmarks-based evaluation. Retrieved August 6, 2006, from http://www.project2061.org/publications/textbook/mgsci/report/index.htm.

Barrow, L. (1990). Elementary science textbooks and potential magnet misconceptions. *School Science and Mathematics, 90*, 716-720.

Beauchamp, W. L., Mayfield, J. C., & West, J. Y. (1958). *Science Problems 3*. Chicago, IL: Scott Foresman.

Brooks, W. O., Tracy, G. R., Tropp, H. E., & Friedl, A. E. (1966). *Modern Physical Science*. New York: Holt.

Carvalho, G. S., Silva, R., & Clement, P. (2007). Historical analysis of Portuguese primary school textbooks (1920-2005) on the topic of Digestion. *International Journal of Science Education, 29*(2), 173-193.

Chall, J. S., & Squire, J. R. (1991). The publishing industry and textbooks. In R. Barr, M. L. Kamil, P. Mosenthal & P. D. Pearson (Eds.), *Handbook of Reading Research* (Vol. II, pp. 120-146). New York: Longman.

Cho, H.-H., Kahle, J. B., & Nordland, F. H. (1985). An investigation of high school biology textbooks as sources of misconceptions and difficulties in teaching genetics and some suggestions for teaching genetics. *Science Education, 69*(5), 717-719.

Colin, P., Chauvet, F., & Viennot, L. (2002). Reading images in optics: students' difficulties and teachers' views. *International Journal of Science Education, 24*(3), 313-332.

Cook, M. P. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education, 90*, 1073-1091.

de Posada, J. M. (1999). The presentation of metallic bonding in high school science textbooks during three decades: Science educational reforms and substantive changes of tendencies. *Science Education, 83*, 423-447.

DeBoer, G. E. (1991). *A history of ideas in science education : implications for practice*. New York: Teachers College Press.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory : strategies for qualitative research*. Chicago: Aldine Pub. Co.

Halliday, M. A. K. (1985). *An introduction to functional grammar*. London ; Baltimore, Md.: E. Arnold.

Han, J., & Roth, W. M. (2006). Chemical inscriptions in Korean textbooks: Semiotics of macro- and microworld. *Science Education, 90*, 173-201.

Hegarty, M., Carpenter, P. A., & Just, M. A. (1990). Diagrams in the comprehension of scientific texts. In R. Barr, M. L. Kamil, P. Mosenthal & P. D. Pearson (Eds.), *Handbook of reading research*. New York: Longman.

Holliday, W. G. (1985). Textbook illustrations: Fact or filler? *The Science Teacher, 57*(9), 27-29.

Hubisz, J. (2003, May). Middle-school texts don't make the grade. *Physics Today,* 50-54.

Iona, M. (1987). Why Johnny can't learn physics from textbooks I've known. *American Journal of Physics, 4*, 299-307.

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching, 39*(6), 522-549.

Kikas, E. (1998). Pupils' explanations of seasonal changes: age differences and the influence of teaching. *British Journal of Educational Psychology, 68*, 505-516.

Kress, G. R., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: the rhetorics of the science classroom*. London: Continuum.

Kress, G. R., & van Leeuwen, T. (1996). *Reading images : the grammar of visual design*. London ; New York: Routledge.

LaSpina, J. A. (1998). *The visual turn and the transformation of the textbook*. Mahwah, N.J.: L. Erlbaum Associates.

Latour, B. (1987). *Science in action : how to follow scientists and engineers through society*. Cambridge, Mass.: Harvard University Press.

Lemke, J. L. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. Martin & R. Veel (Eds.), *Reading science*: Routledge.

Linn, M. C., & Hsi, S. (2000). *Computers, Teachers, Peers: Science Learning Partners*. Mahwah, NJ: Lawrence Erlbaum Associates.

Lynch, M., & Woolgar, S. (1990). *Representation in scientific practice* (1st MIT Press ed.). Cambridge, Mass.: MIT Press.

Macdonald-Ross, M. (1979). Scientific digrams and the generation of plausible hypotheses: An essay in the history of ideas. *Instructional Science, 8*, 223-234.

Mayer, R. E. (1993). Illustrations that instruct. In R. Glaser (Ed.), *Advances in Instructional Psychology* (Vol. 4, pp. 253-284). Hillsdale, NJ: Lawrence Erlbaum.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge ; New York: Cambridge University Press.

Mayer, R. E., Steinhoff, K., Bower, G., & Mars, R. (1993). A generative theory of textbook design: Using annotated illustrations to foster meaningful learning of science text. *Educational Technology Research and Development, 43*(1), 31-43.

Morrison, E. S., Moore, A., Armour, N., Hammond, A., Hayson, J., Nicoll, E., et al. (1993). *Science Plus: Technology and Society*. Austin, TX: Holt, Rinehart, & Winston.

Nathan, M. J., Long, S. D., & Alibali, M. W. (2002). The Symbol Precedence View of Mathematical Development: A Corpus Analysis of the Rhetorical Structure of Textbooks. *Discourse Processes, 33*(1), 1-21.

Pinto, R., & Ametler, J. (2002). Students' difficulties in reading images. Comparing results from four national research groups. *International Journal of Science Education, 24*(3), 333-341.

Pozzer, L. L., & Roth, W. M. (2003). Prevalence, function, and structure of photographs in high school biology textbooks. *Journal of Research in Science Teaching, 40*(10), 1089-1114.

Pozzer, L. L., & Roth, W. M. (2004). Making sense of photographs. *Science Education, 89*, 219-241.

Ramadas, J. (1982). Use of ray diagrams in optics. *School Science, 20*(9), 10-17.

Ravitch, D. (1983). *The troubled crusade: American education 1945-1980*: Basic Books.

Roth, W. M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching, 36*(9), 977-1019.

Rudolph, J. L. (2002). *Scientists in the classroom: The cold war reconstruction of American science education*: Macmillan.

Schnotz, W. (2002). Toward an integrated view of learning from text and visual displays. *Educational Psychology Review, 14*(1), 101-120.

Smith, R. G., Ballinger, J. T., & Thompson, M. (1993). *Merrill Physical Science*: Glencoe/MacMillan.

Stern, L., & Roseman, J. E. (2004). Can middle-school science textbooks help students learn important ideas? Findings from Project 2061's curriculum evaluation study: Life science. *Journal of Research in Science Teaching, 41*(6), 538-568.

Stieff, M. (2005). *Dichotomous use of external representations in science learning*. Paper presented at the 2005 Annual Meeting of the American Educational Research Association.

Stylianidou, F., Ormerod, F., & Ogborn, J. (2002). Analysis of science textbook pictures about energy and pupils' readings of them. *International Journal of Science Education, 24*(3), 257-283.

Sullivan, J. P. (2008). The use of photographs to portray urban ecosystems in six introductory environmental science textbooks. *Journal of Research in Science Teaching, 45*(9), 1003-1020.

Wampler, J. M. (2002). Misconceptions - A column about errors in geoscience textbooks: Misconception of energy release in earthquakes. *Journal of Geoscience Education, 50*(5), 620-623.

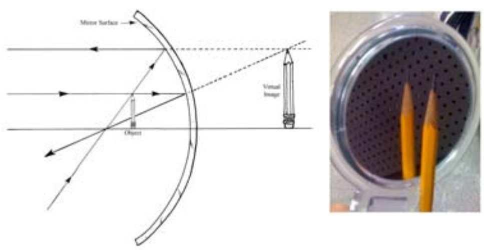
Woodward, A. (1992). Do illustrations serve an instructional purpose in US textbooks? In B. K. Britton, A. Woodward & M. Binkley (Eds.), *Learning from textbooks: Theory and practice*. Hillsdale, NJ: Lawrence Elrbaum Associates.

Woodward, A., & Nagel, K. C. (1987-1988). Old wine in new bottles: An analysis of changes in elementary social studies textbooks from old to new editions. *Book Research Quarterly, 3*(4), 22-33.

Figure 1

(a) Brooks, et al. (1966)

(b) Beauchamp, et al. (1958)



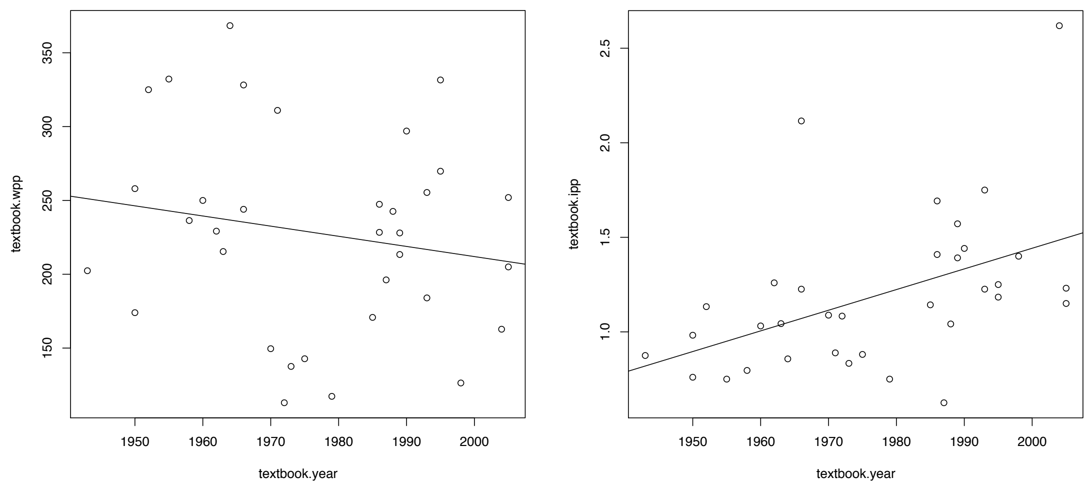
(c) R.G. Smith, et al. (1993)

(d) Morrison, et al. (1993)

Representation	Photograph	Line drawing	Schematic Drawing
Brooks, et al. (1966)			✓
Beauchamp, et al. (1958)	✓		
R.G. Smith, et al. (1993)	✓		✓
Morrison, et al. (1993)		✓	

Figure 1: Examples of examined representations and graphic media codes that were assigned.

Figure 2



(a) (b)

Figure 2: (a) Average words per page over textbook publication year and (b) average representations per page over textbook publication year.

Figure 3

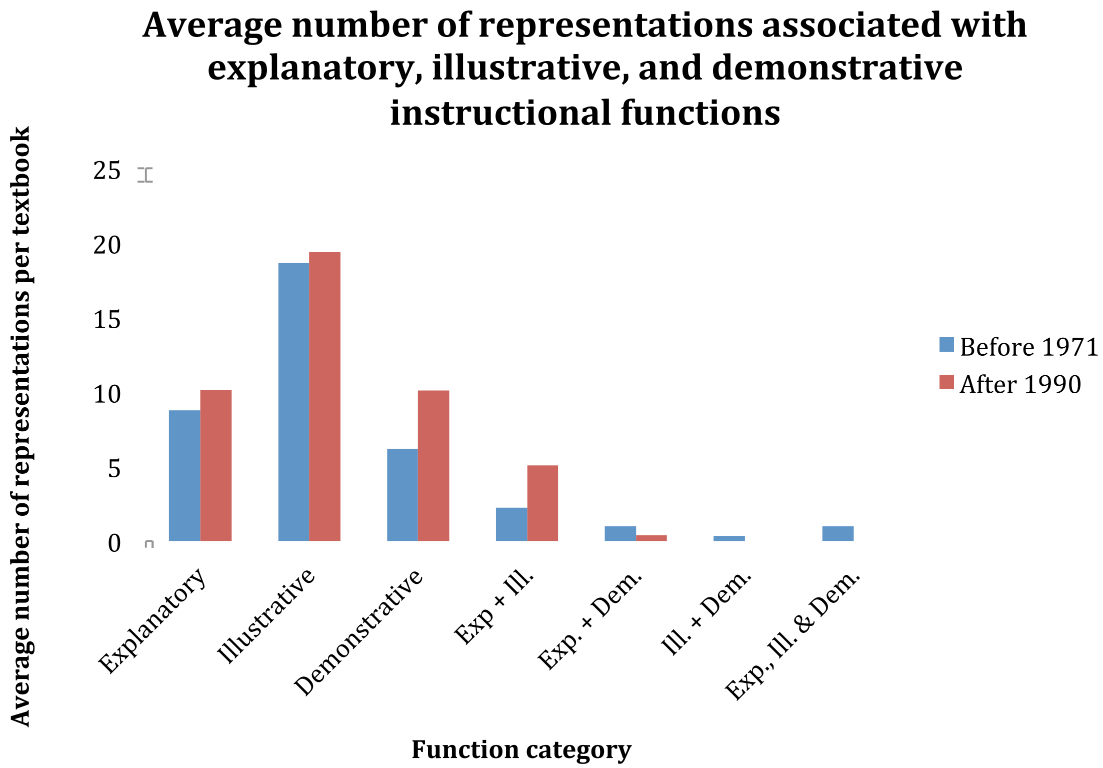
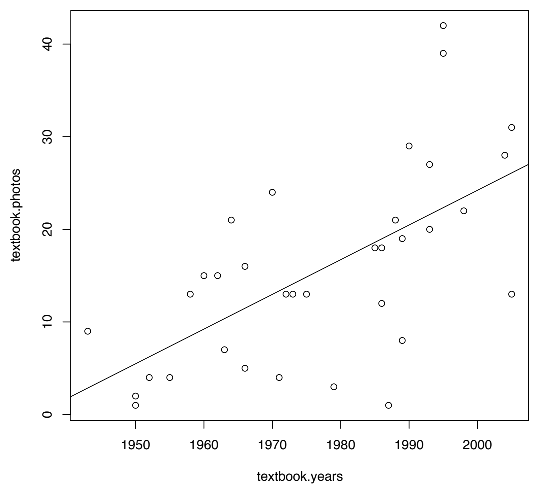
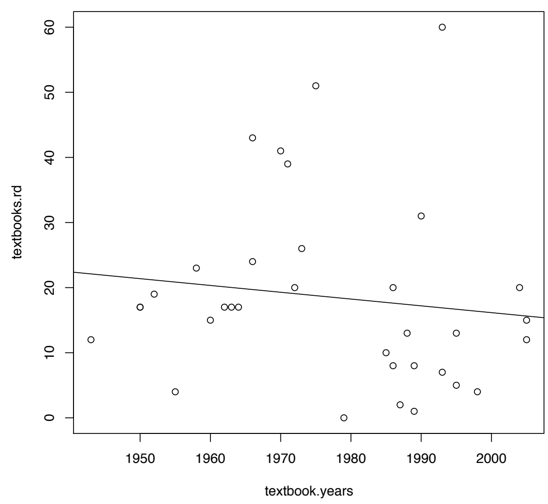


Figure 3: Average number of representations associated with instructional functions, pre-1971 vs. post-1990

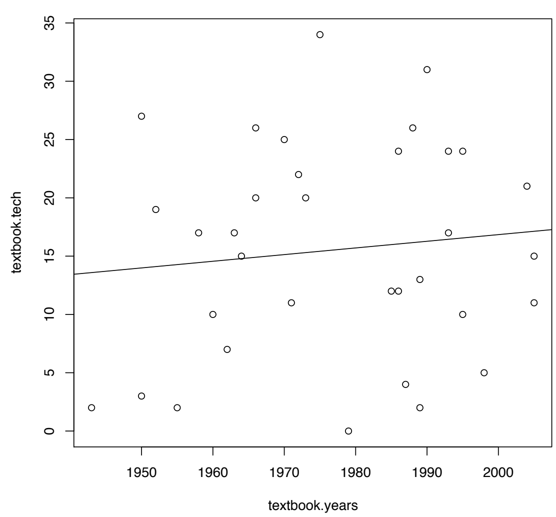
Figure 4



(a)



(b)



(c)

Figure 4. (a) Count of photos over publication year (b) Count of line drawings over publication year (c) count of schematic diagrams over publication year.

Figure 5

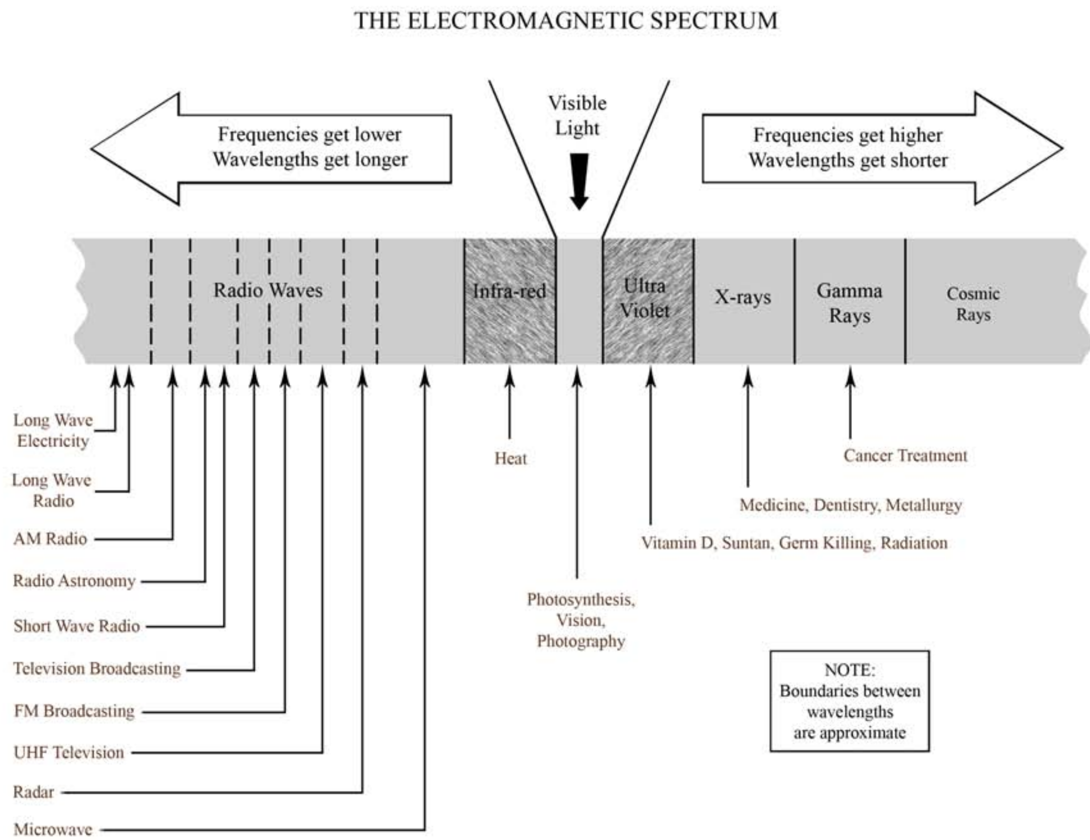


Figure 5: Electromagnetic spectrum from Oxenhorn (1970), p. 147.

Figure 6

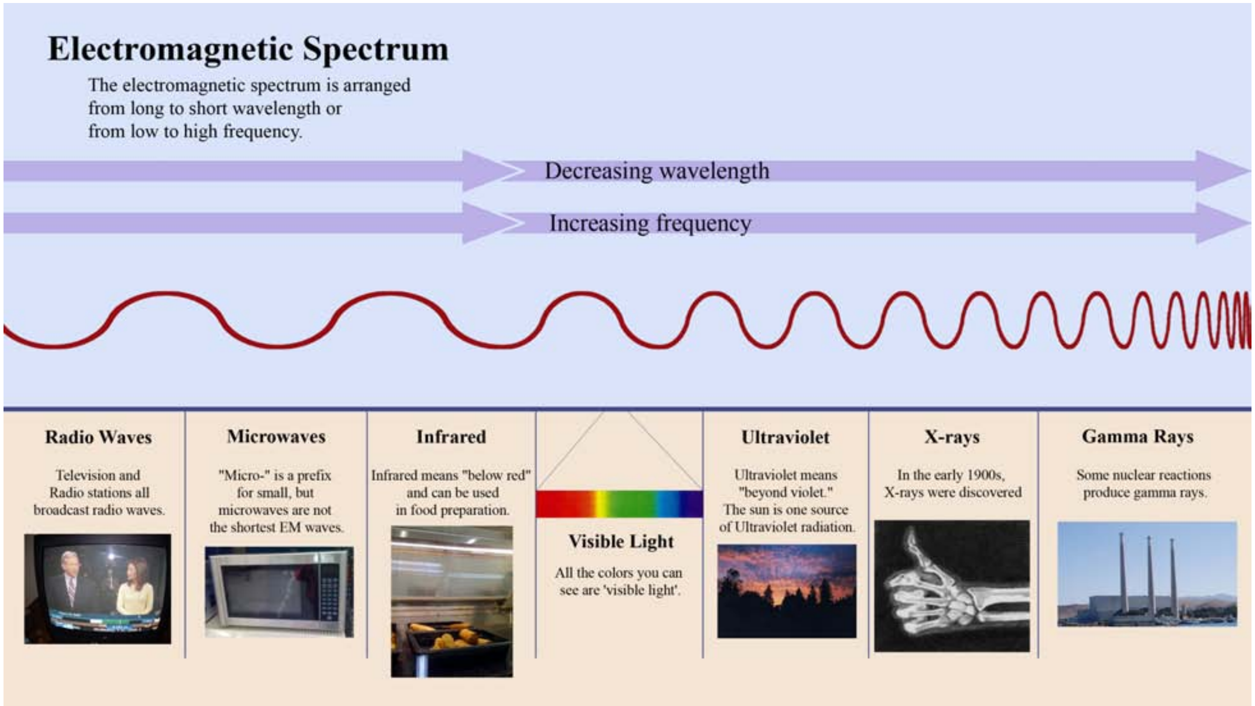


Figure 6: Electromagnetic spectrum from Bogford, et al. (2004), p. 568-569

Figure 7

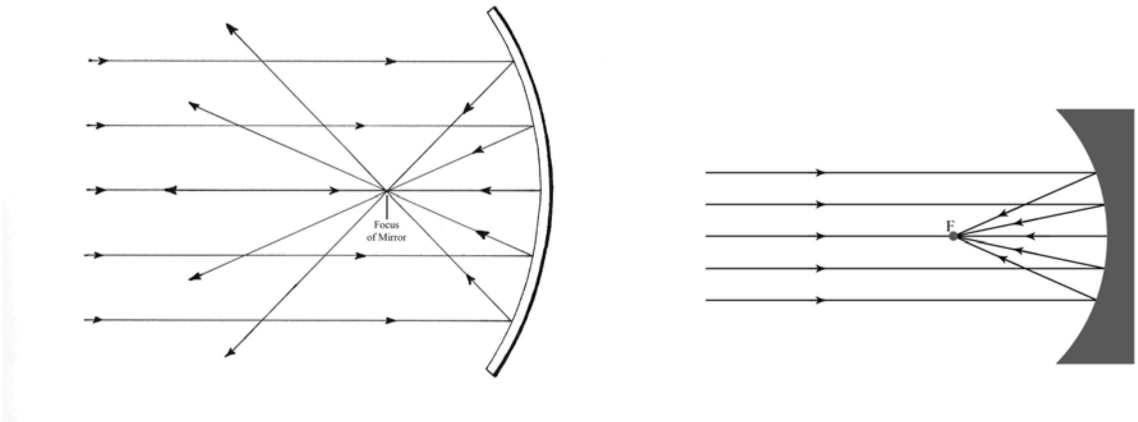


Figure 7: Light ray paths after reflection from a concave surface from Painter & Skewes (1950) and Oxenhorn (1970)

Figure 8

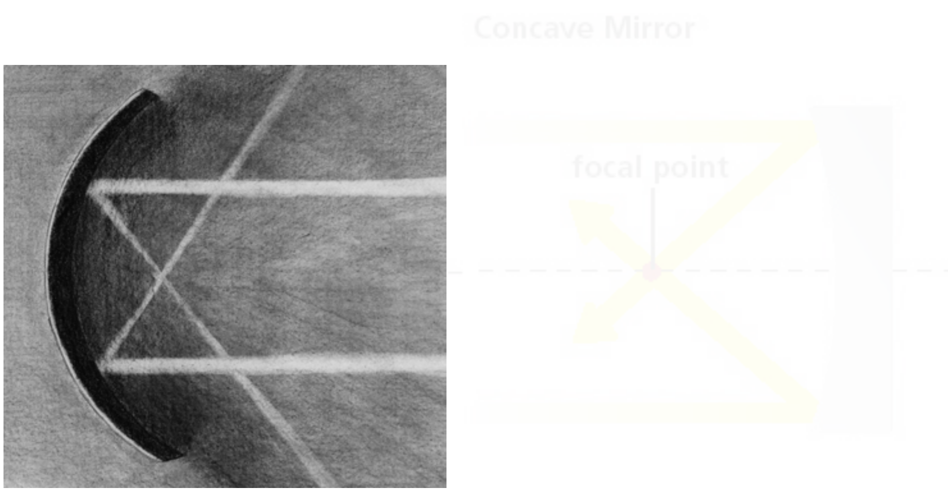


Figure 8: Light ray paths after reflection from a concave surface from Bogford, et al. (2004) and McDougal Littell (2005)

Figure 9

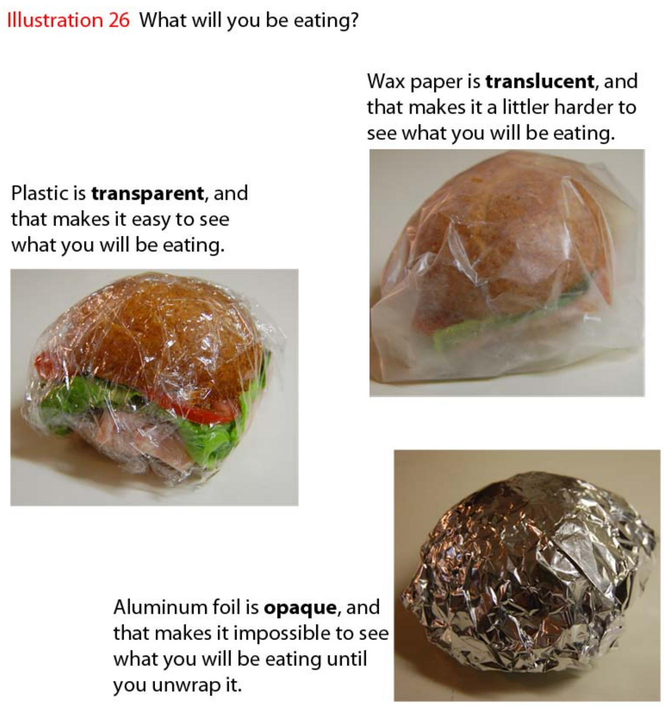


Figure 9: Representation of transparency, translucency, and opacity (Bogford, et al., 2004).

Figure 10

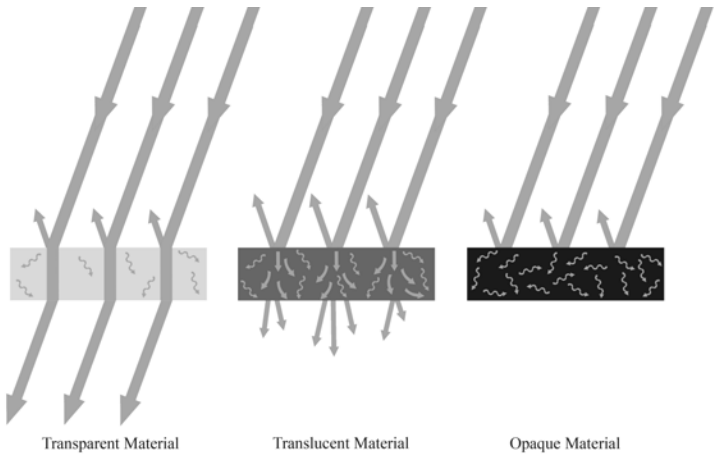


Figure 10: Representation of transparency, translucency, and opacity (Beauchamp, et al., 1958).