The Integration of Text and Image, Its Cognitive Impacts for Learning with Media, and Science Instruction: A Ph.D. in Design Study

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Abstract: This paper outlines a recent quasi-experimental study in fulfillment of the Ph.D. in Design. The study stands as an example of new research in the formation of a discipline of design (from a practice or field), according to a statistical model most consistent with psychological research. (The Ph.D. in Design can also extend into historical and argumentative models of research.) The study outlined (Peterson, 2011) addressed the design of instructional media both holistically and authentically by focusing on text–image relationships at the level of design strategy. Three text–image integration strategies are proposed and illustrated herein: prose primary (PP), with a central prose column and marginal imagery; prose subsumed (PS), with shorter prose segmented by imagery; and fully integrated (FI), where smaller textual chunks populate imagery. Over 150 middle school students participated in this study. Text–image integration strategies were tested for comprehension of abstract concepts, sense of difficulty, and interest level. Subjects completed comprehension tests using the supplied media. They rated their sense of difficulty and their interest in science textbook pages designed according to the outlined strategies. Their selections of interest strongly favored higher levels of text–image integration, such that FI was rated more interesting than PS, which was in turn more interesting than PP. Interest-level results were rated reliable and significant at a 95% confidence level. Comprehension results were less conclusive, with one treatment of FI proving more effective than PP, while two other treatments were found statistically insignificant. There was no suggestion that text–image integration strategy impacts sense of task difficulty.

THE INTEGRATION OF TEXT AND IMAGE, ITS COGNITIVE IMPACTS FOR LEARNING WITH MEDIA, AND SCIENCE INSTRUCTION

A PH.D. IN DESIGN STUDY

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INTRODUCTION

This study approaches graphic layout from the designer's implicit strategy for integrating text and image in media, and how that ultimately models or facilitates a reader's experience. The integration of text and image has significant cognitive implications for readers. Here I will focus on the secondary science textbook and its audience. The science textbook is in a peculiar situation: its is a largely unwilling readership. It is also dependent upon imagery for much of its explanatory power. The science textbook is an ideal demonstration of text–image integration not only because of its inherent demand for such integration, but because it has specific cognitive goals—learning outcomes—that we can assess. Learning is an eminently testable situation.

I will outline three distinct strategies for the integration of text and image and report on a doctoral study involving 158 seventh grade students at a middle school in North Carolina. The study looks at the impact of text–image integration on comprehension of abstract concepts, sense of task difficulty, and interest level in both subject matter and graphic layout.

The study was conducted spring 2011 towards fulfillment of the Ph.D. in Design at North Carolina State University under the direction of Meredith Davis. Nilda Cosco, James Minogue, and John Nietfeld also served on the doctoral committee. My thanks to them.

The present paper is a roughly 4,000-word summary of a 60,000-word dissertation document (Peterson, 2011). I will discuss the findings and their implications, but I will not provide any significant detail on such issues as item analysis protocols, reliability estimates, hypothesis testing, or measured values in general. The reader may assume that for most assertions more detail can be found in the dissertation, which follows the same basic outline evident here. This is not to suggest that proper research should rely on trust from its reviewers. I am attempting a summary of an extensive study that is appropriate for a readership of graphic design educators in limited space. Those more technically inclined are encouraged to consult the exhaustive dissertation, which is available online (see citation).

CONCEPTUAL FRAMEWORK

American textbooks aren't simply resources for teachers. Textbooks play an ongoing creative role in classroom instruction (Woodward, 1993a). Because the textbook represents such a demanding and complex production problem, instructional goals are too often overlooked or underdeveloped (Woodward, 1993b; Pettersson, 1998), especially considering the challenge of translating a reading experience into a learning experience. The process of designing a textbook follows the development of a prepared text, and naturally the typical layout reflects this: a continuous prose is flanked by marginal imagery that was developed later in production. Not surprisingly textbook illustrations tend to "support" or reiterate textual content rather than extending it (Woodward, 1993b). If images don't offer anything new, or are primarily intended to sell textbooks (Pettersson, 1998, p. 7), it is sensible that readers don't appear motivated by them (Levin, 1979). Textbooks are assessed in terms of content provision (in textual form), and not how that content is functionally delivered or processed.

In contrast, the transactional theory of reading (Rosenblatt, 1978) views a text in terms of a reader's experience of it, as "an event in time" (p. 12). Such a theory naturally aligns with our understanding of the learning process. We're far past believing that classroom instruction is simply a matter of the teacher saying the right things, and those things thus being poured into students' heads. There is a structure to reader experience that shifts the focus away from simply *what* a textbook communicates to *how* it goes about communicating (Ciardi, 1959; Fish, 1976). This latent activity is programmed into text, image, and their relationships.

It stands to reason that a designer who is concerned with little more than including supplied textual content, making appropriate visual decisions, and rendering text legible, is unlikely to know how his or her decisions may be modeling a reader's experience.

A fundamental way we understand concepts and phenomena is through metaphorical structuring, by selectively mapping characteristics of one thing onto another in a never-ending web of interrelated knowledge (Johnson, 1987). What metaphor is a textbook designer operating under? Is the textbook a container, or an experience? Under a book-as-container metaphor, the reader merely extracts information, and inclusion, appropriateness, and legibility are ample considerations. Under a book-as-experience metaphor, such considerations appear insufficient (though they persist yet), and focus shifts to the reader and his or her cognitive processing whilst reading.

Cognitive load theory (Plass, Moreno, & Brünken, 2010) accounts for the limited resources humans bring to bear in interpretational processes. Human working memory, the basic architecture of consciousness, includes dedicated resources for processing linguistic and imaginal information (Baddeley, 1998; Sadoski & Paivio, 2001). While the amount of information that can be held and manipulated in working memory at any given time is especially limited (Cowan, 2000; Van Merriënboer & Sweller, 2005), schematic structures in long-term memory can increase the function of working memory (Mandler, 1984). So too can structures on the page—information formatted as text and image and arranged according to meaningful relationships—which serve as a form of external cognition (Vekiri, 2002, p. 282). An astute designer can extend a reader's cognitive capabilities.

Cognitive load is a quantification of the mental faculties available and utilized during a task. In the case of a science textbook, it's not just a task of reading, but learning. A task has a fixed inherent difficulty given a learner's expertise, its intrinsic load. For the remaining available cognitive load, the design of media determines how much is extraneous (due to "inefficient" visual design) and how much can prove germane to learning. Germane cognitive load is where new long-term memory structures are built, or where we learn in the traditional sense. Simple factors can impact cognitive load. For instance, the physical distance between related pieces of information on the page—separated but supplemental text and image—can increase extraneous load as readers are forced to hold information in working memory rather than perceptually experience it as integrated (Schnotz & Kürschner, 2007, p. 481). However abstract cognitive processing may appear, designers manipulate it in the most concrete ways.

According to cognitive load theory, learning is the product of germane cognitive load, and involves interaction between working memory and long-term memory (Schnotz &

Kürschner, 2007, pp. 477, 492–493). Comprehension (called *understanding* in cognitive load theory) occurs entirely in working memory, and is achieved when all necessary elements of information, at any given time, are processed together (p. 477). Again, inefficient design contributes to extraneous cognitive load and thus detracts from the resources otherwise available for germane load.

This study seeks to interrogate the effects of text, image, and their interrelationships on the reader's task. The ultimate concern is learning; the immediate concern is comprehension. This study limits its scope to the latter.

There are numerous prescriptions for cognition-sensitive graphic design in the literature on textbook illustration, dual coding theory, and cognitive load theory (Plass et al., 2010; Sadoski & Paivio, 2001; Vekiri, 2002). But it is difficult for a designer to work from a list of prescriptions, and much of the work in psychology on layout relationships is done without complex and authentic design materials. A general cognitive view of the learning process is that it occurs when learners "select and build cognitive connections among pieces of knowledge" (Mayer, Steinhoff, Bower, & Mars, 1995, p. 32).

I propose a more general means of approaching design, at the level of strategy, which is more sensitive to how designers work and targets more complex and authentic outcomes. In this case, the outcome is print media, as two facing pages that serve as the basic experiential unit of a science textbook.

The fundamental structure of a page lies in the constitution of text and image. Most illustrated books conform to a prose primary strategy. *Prose primary* is expressed as a central prose column (or columns) with marginal imagery. There is a proper reading order, according to the inherent structure of prose, which must be broken any time a reader decides to attend to a supplemental image. How might comprehension (and thus learning) change under a state of greater text–image integration?

An extreme form of text–image integration is the diagram. A fully integrated strategy of text–image integration is expressed as an imaginal space, or arrangement of imaginal spaces, for which there is no proper reading order. The reader has complete control over attention patterns (it is a parallel system), with practically any locus a viable entry point. Text is broken up into discrete chunks embedded in the imagery, and in meaningful positions. There is text, but no longer a prose.

A prose subsumed strategy takes the middle ground. Here images serve as entry points into short prose structures. *Prose subsumed* is expressed as a series of individual image–caption systems. The reader has more control over reading order than in *prose primary,* with any of the image–caption systems a valid entry point, but within each its own prose structure exerts control.

These three strategies for integrating text and image—prose primary (PP), prose subsumed (PS), and fully integrated (FI) (Figure 1)—serve as the basic model studied here. This is not just a model of layout, which would concern the arrangement of *given* elements on a page. This concerns the strategy that produces layouts, where the elements' codes (text or image) are in play. As the relationships are meaningful and not simply locational, a shift from one strategy to another involves the manipulation of the elements

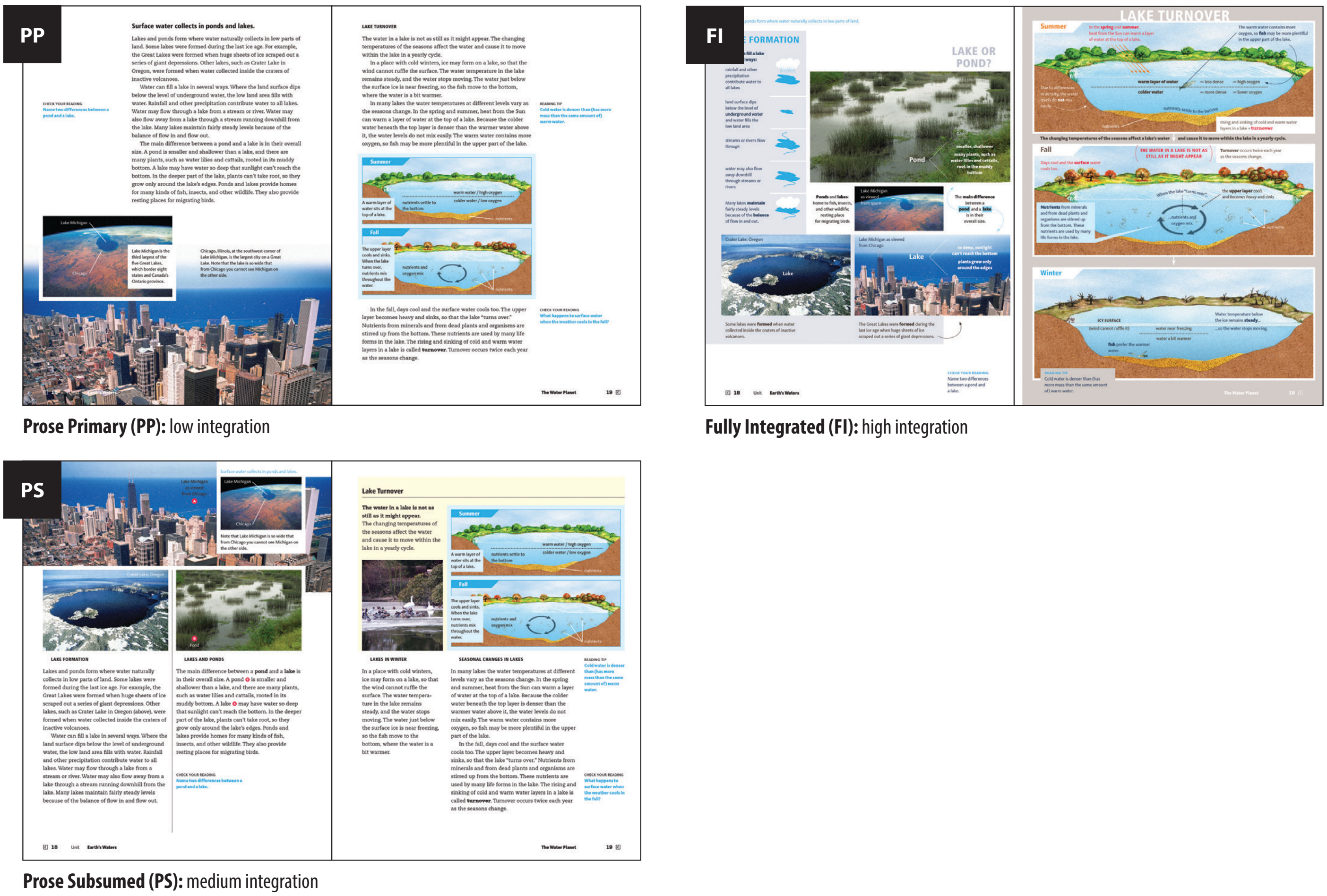

Figure 1: Three text–image integration strategies (treatment test #2 forms). Adapted from *MCDOUGAL LITTELL SCIENCE, North Carolina Edition, Student Edition, Course 3,* by Trefil, Calvo, & Cutler. Copyright © 2005 by McDougal Littell. All rights reserved. Adapted and reprinted by permission of the publisher, Houghton Mifflin Harcourt Publishing Company. Any further use is strictly prohibited unless written permission is obtained from Houghton Mifflin Harcourt Publishing Company.

themselves—the elements change as the layout develops. The relationships are tight and interconnected.

The primary research question becomes: (1) How does strategy for text–image integration in instructional media for middle school students impact their comprehension of abstract relationships in science material?

The secondary research questions explore the same independent variable (text–image integration strategy) through other dependent variables: (2) perception of task difficulty, (3) interest level in subject matter, and (4) interest level in instructional print media. These variables should ultimately impact learning through the reader's approach to the learning task.

Comprehension has already been covered. According to cognitive load theory, mental effort is an artificial ceiling to cognitive load, as a learner can fail to bring his or her full faculties to bear. Perception of task difficulty has been deemed a better indicator of instructional effects than what would seem to be more direct, actually asking subjects about their perceived mental effort (Brünken, Plass, & Leutner, 2003, p. 56).

The interest level measures (in subject matter and in instructional print media) align closely with the psychological construct of situational interest, where environmentally derived interest affects many aspects of learning (Schraw & Lehman, 2001, pp. 23–24).

METHODOLOGY

SETTING & SUBJECTS

Both the North Carolina State University Institutional Review Board and the Wake County Public School System Research Review Committee approved this research study. The participating school is urban, with a relatively high percentage of limited English proficiency students, a relatively high percentage of African-American students, and a relatively low percentage of white students (WCPSS, 2011, pp. 35, 44 & 94; USDOE, 2009).

One hundred fifty-eight (158) students both consented to the study and survived removal criteria (84 female and 74 male). Subjects participated in the study on four consecutive Mondays in their regular science classes, making this a quasi-experimental study. Research assistant Rachael Huston and I proctored sessions in concurrent classes. Cluster sampling, where subjects in each class (cluster) were randomly assigned to relatively class-balanced groups, protected against classroom differences.

TEST FORMS

This study considers design holistically, seeking authenticity and ecological validity, by identifying strategies for text–image integration and providing subjects with fully realized textbook spreads. Each of the three treatment sessions presented one subject matter across the three strategies. Each subject experienced each strategy only once in random order.

I generated the forms by modifying existing textbook spreads systematically according to the outlined text–image integration strategies. The textbook used (Trefil, Calvo, & Cutler, 2005) follows a general prose primary strategy. Conversion was most time-consuming for fully integrated forms, where a significant amount of the information was transformed from linguistic (text) to imaginal (image) codes. All modifications were made according to meaningful relationships within the content. For instance, prose-based descriptions of what happens in a lake in the winter were broken down into smaller textual chunks and placed in appropriate spots within a cross section of a winter lake. When text was reduced from *prose primary* for the more integrated strategies, new images were added. For the set of forms shown in Figure 1, word count decreased from 633 to 624 for *prose subsumed,* and down to 492 for *fully integrated*.

DATA COLLECTION

Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001) suggests distinct factual and conceptual levels of knowledge. Factual knowledge has a low level of abstraction while conceptual knowledge has greater complexity and is organized. Performance tests were developed to measure comprehension according to these two levels of knowledge. Six multiple-choice test items were developed for each knowledge type per treatment test, culled from longer lists used in pilot tests with undergraduate students. Conceptual knowledge items required the reader to put together multiple sources of information, form inferences, or both. Best practices were observed in the development of test items (Reynolds, Livingston, & Willson, 2006).

All test instruments utilized Survey Gizmo, which the subjects accessed on classroom laptops. The forms were printed in color and available throughout testing.

Following the twelve test items, subjects completed a task difficulty assessment (a 6-point forced-response Likert scale), a task difficulty explanation (constructed response), and a subject matter interest level inventory (4 items with 5-point Likert scales).

A pre-test measured subject mastery using 10 multiple-choice textbook review items from earlier in the school year, and measured personal confidence in the subject of science, or *science self efficacy,* using eight 5-point Likert scales (from Nietfeld, Cao, & Osborne, 2006).

A post-test presented subjects with all three versions of each treatment test form page (for a total of 6 page comparison sets) in random order. This effectively revealed the basic nature of the study, which had not yet been explained to the subjects. The page designs were shown at thumbnail size (Figure 2), such that subjects were responding to the *gist* of the visuals: a first impression or approach. Subjects first selected the most interesting page from the sets, and then were given the same sets and selected the least interesting.

RESULTS

ITEM ANALYSIS & RELIABILITY

Item analysis for the factual and conceptual knowledge treatment test batteries was conducted according to strict protocols, including item difficulty indices, item discrimination indices, item-total correlation coefficients, and distracter analyses. This was done according to standards set by Reynolds, Livingston, and Willson's *Measurement and Assessment in Education* (2006). This resulted in the removal of one test item total for each treatment test. All calculations for this study were performed using JMP statistical software by SAS.

The six sequence groups (subjects receiving the strategies in the same order) were found to be equivalent, according to ANOVA, on review test scores, aggregate treatment test scores, and science self efficacy ratings.

Internal reliability of all test batteries and Likert inventories was calculated using Cronbach's alpha (α) according to referenced standards of practice (Cortina, 1993, p. 102; Reynolds et al., 2006, pp. 93–97). A summary of reliability estimates is provided in Table 1.

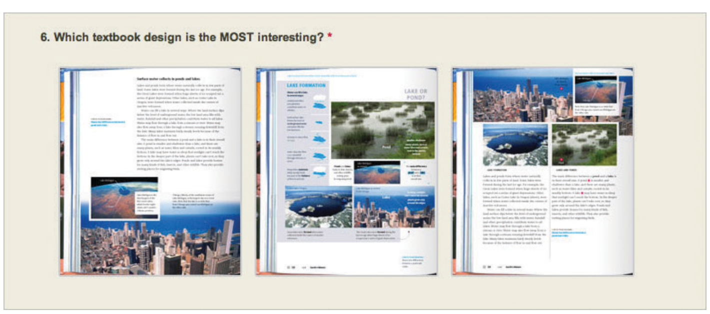

Figure 2: Strategy interest level item (randomized here to PP, FI, PS).

Table 1: Summary of reliability estimates.

Summary	α	Rating
Review Battery	0.5284	Dubious
Treatment #1 Full Set	0.6234	Acceptable
Treatment #2 Full Set	0.7821	Good
Treatment #3 Full Set	0.7156	Good
Factual #2 Set	0.6456	Acceptable
Conceptual #2 Set	0.6757	Acceptable
Conceptual #3 Set	0.6386	Acceptable
Other Fact. & Con. Sets	<.6000	Dubious
Science Self-Efficacy	0.8507	Good
Interest #1 Inventory	0.8510	Good
Interest #2 Inventory	0.8638	Good
Interest #3 Inventory	0.9013	Excellent
Task Difficulty Scales	0.7339	Acceptable
Session Duration as a Set	0.8908	Good
Adj. Direct Interest	0.8649	Good

The distinction between factual and conceptual test item sets is difficult to justify given the reliability ratings. Only in treatment #2 can the factual and conceptual sets be considered individually. The first treatment test was found to be weaker overall than the other two.

COMPREHENSION

The primary research question probes the relationship between text–image integration and comprehension. In all treatment tests, subjects using the fully integrated forms scored higher on comprehension than those using either of the other forms (Figure 3). However, only treatment #2 provided statistically significant results. In treatment #2, fully integrated (FI) scores were higher than prose subsumed (PS) scores, which in turn were higher than prose primary (PP) scores. It was only the relationship between FI and PP that proved significant. The treatment #2 factual set (but not the conceptual set) had both FI and PS groups significantly outperforming the PP group. As would be expected, conceptual questions proved more difficult than factual questions in each treatment test.

It is encouraging that the most reliable of the treatment tests is the one that produced significant results. It is also encouraging that all treatments, though only one was found to be significant, exhibited the same trend of FF highest in comprehension scores. (PS was not always above PP, however.)

INTEREST IN INSTRUCTIONAL PRINT MEDIA

The fourth research question inquires into the reader's interest in media design itself, not its subject matter. This issue was addressed in a post-test, completed immediately after treatment #3 on the final Monday of the study. When faced with isolated page sets of PP, PS, and FI, subjects tended to select FI as the most interesting and PP as the least interesting (Figure 4). The true means for the individual strategies, when estimated using 95% confidence intervals, are remarkably distinct and arranged in a logical order, with greater text–image integration corresponding with higher interest level assessments. Among this population of subjects, FI is the most interesting and PP the least interesting.

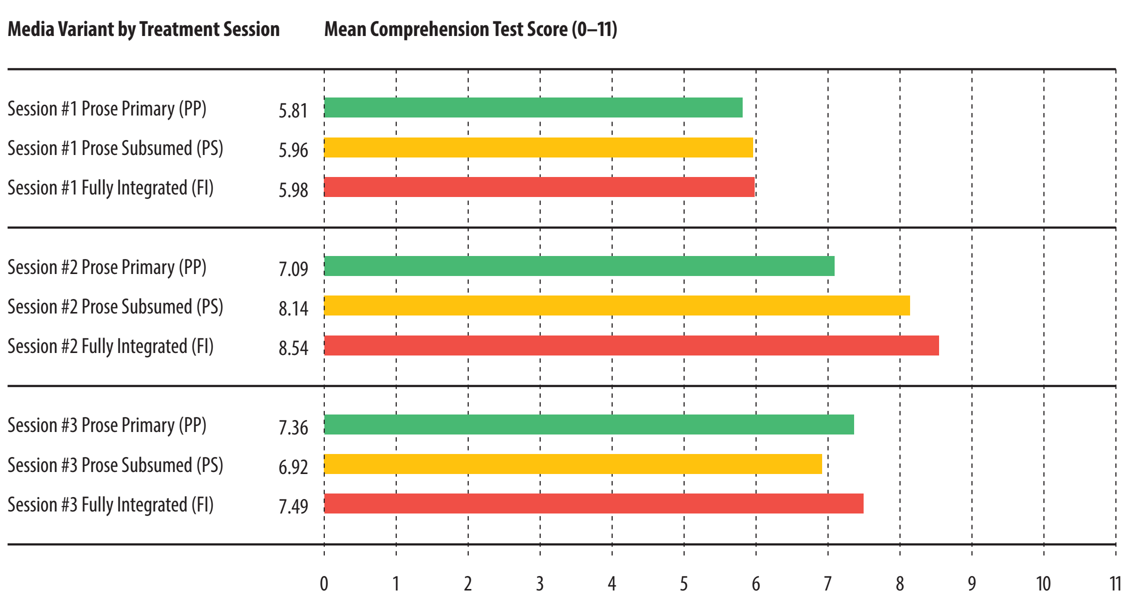

Figure 3: Comprehension of abstract relationships, test score means (combined factual and conceptual items).

These are the lone unequivocal results of the study (comprehension results were positive but partial).

OTHER RESULTS

There is no evidence that text–image integration strategy impacts the sense of task difficulty (the second research question), where the task is extracting factual and conceptual knowledge from instructional media. Interest in subject matter (the third research question) also appears overall unaffected by text–image integration strategy. There was one case of significant differences (PS>PP) but no consistent pattern overall, so that result in questionable.

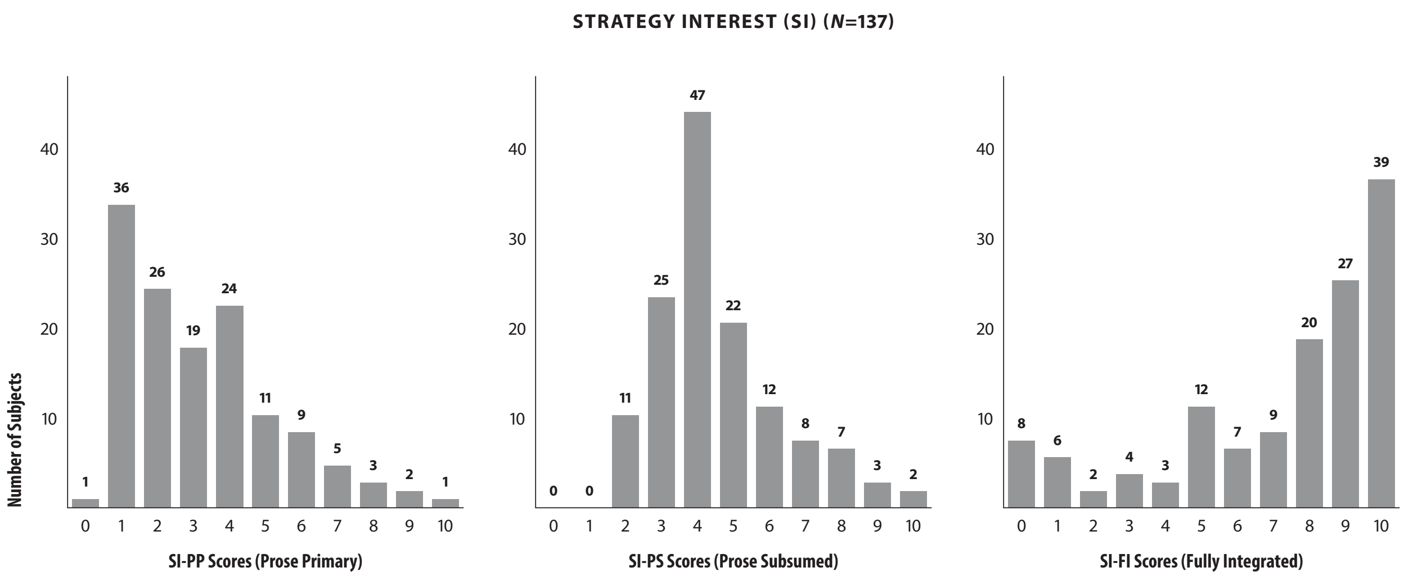

Figure 4: Interest in instructional print media strategy, individual strategy score totals (*N*=137). Base score = 5. Each selection of "most interesting" = +1. Each selection of "least interesting" = −1. A score of zero could indicate no selections or a balance of most and least interesting selections. (Due to a glitch in the instrument, only 5 comparisons apiece exist for most and least interesting selections, below the planned 6, resulting in an individual score range of 0–10.)

SUMMARY OF RESULTS

There are indications that higher levels of text–image integration may promote comprehension in middle school students (at least in science). The fully integrated strategy did produce the highest comprehension scores, but only once was the effect deemed statistically significant. This begs further investigation.

It is more certain that middle school students find higher levels of text–image integration to be more interesting. These results also proved consistent with the assumption that *prose primary, prose subsumed,* and *fully integrated* represent a logical relationship of increasing text–image integration.

Other variables gave little to no indication of a relationship to text–image integration strategy: sense of task difficulty and mediated interest in subject matter especially of note.

DISCUSSION

IMPLICATIONS ACROSS DISCIPLINES

The implications of this study on text–image integration strategy touch on multiple disciplines. Most obvious is graphic design and science education. For graphic design, the conceptual framework promises to connect what is often an instinctual practice (the experience of making design with “the gut”) to specific cognitive outcomes that are sensitive to human processing architecture.

For science education, text–image integration strategy offers a new means to evaluate instructional media. It is less prescriptive, perhaps, than other models, but counters this with its ability to identify more holistic and authentic materials. What it lacks in specific prescriptions it makes up in the breadth of its concern. Science as a target subject was chosen partly as a convenience, and is not the only highly visual major course of study in K-12. History also presents many opportunities for visualizing information.

Much of the work that this study builds on comes from psychology, where its descriptive power may prove beneficial. It represents a potential collaborative direction connecting graphic design to psychology.

This study should be of interest to textbook publishers. Of course, even if the prose primary strategy is found to be less desirable than higher levels of text–image integration, it will remain the most convenient strategy from a production standpoint. Fully integrated design is more time-consuming. Favoring *fully integrated* would also require a restructuring of the basic publication model, where currently a text is developed before page layout is addressed. These implications are not minor, and potential implementation is not cheap.

FUTURE WORK

Some of the suggestions for future work are especially obvious. It would be desirable to repeat this study with some combination of more extensive treatment forms, more comprehension items, more treatment sessions, more accurate measures of session duration (collected here but deemed not valid), and more subjects.

But the question of what factors might drive differential comprehension results (were such results more pronounced if measured more accurately) is less obvious. How might results change when comparing native English speakers to those classified as limited English proficiency? *Prose primary,* the dominant strategy in textbooks, requires more advanced language comprehension, while *fully integrated* converts some textual information to imagery. Are limited English proficiency students considerably less *visually* literate? It is doubtful, and as such higher levels of text–image integration may serve as a partial language equalizer in the classroom.

Likewise, it would be interesting to compare relative success across text–image integration strategies for groups of high performing and low performing students. High performing students have had success with *prose primary.* Perhaps their low-performing counterparts would do especially well with *fully integrated.*

If *fully integrated* were to prove superior overall for middle school students, does the trend continue through higher grades? Is *fully integrated* even a viable strategy for more advanced content?

From the perspective of graphic design, there is more to be learned about the basic construct of text–image integration at the level of strategy. How might the classification of strategies change or expand when looking at explicitly interactive media? How might the general strategies be broken down into individual text–image relationships that contribute to an overall strategy? What are the devices that designers can utilize?

I am currently working on a funded study of the cognitive function of imagery—one part of text–image integration. I also began to break down the range of possible individual text–image relationships in media during the course of my doctoral study, assisted by Rachael Huston, but ceased development and removed any discussion of that investigation from the dissertation. This work will contribute to what might perhaps become a complete performative model of meaningful media structure. But it remains to be seen.

At its most modest, this study was about establishing text–image integration strategy as a holistic and authentic construct, with potential for connecting the structures of media to cognition. It is presumptuous to estimate the idea's efficacy at such an early stage of development, but it may prove useful in science education, psychology, and graphic design practice and education. As such I hope it serves as one productive interdisciplinary bridge as graphic design continues to transition from a practice to a research-inclusive discipline.

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