Establishing and Applying Literature-Based Criteria for Effective Communication of Science to Novices Via Introductory Geology Textbooks

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ABSTRACT

Textbooks are widely used in higher education by instructors and students. Therefore, it is useful to examine how textbooks present information because textbook design impacts how well students learn from them. This study has two parts. First, within the framework of the cognitive load and dual-coding theories, a set of recommendations based on research on how novices learn from printed materials was developed with the goal of establishing a set of best practices to improve student learning. These recommendations include integrating text and figures and minimizing extraneous geologic vocabulary. Any information in printed form, such as textbooks, lab manuals, and informative handouts, could benefit by using these recommendations in their design. Second, a subset of the recommendations was systematically applied to analyze the four introductory geology textbooks with the largest market share. The results of this analysis indicate that students would benefit from textbooks that are more closely aligned with how novices learn best. [DOI: 10.5408/16-205.1]

Key words: textbook, cognitive, learning theory, communication

INTRODUCTION

Importance of Textbooks

Textbooks are used extensively in education by both students, who use them initially to learn and later as a reference (Bierman et al., 2006), and by instructors, who refer to them when determining the content for a class (e.g., Tulip and Cook, 1993; Chambliss and Calfee, 1998; Henke et al., 1999; Issit, 2004; Davila and Talanquer, 2010). Textbooks can also change student attitudes towards science (Kloser, 2013). Therefore, textbooks need to be carefully written so students can gain meaning and a deep level of understanding from them, rather than treat them as something to memorize (Tulip and Cook, 1993). However, many textbooks are not written based on how students learn (Carpenter et al., 2006).

Prior Research on Textbooks

Several studies have examined college-level textbooks in general, and a few have examined geology textbooks specifically, with each describing an aspect of pedagogical effectiveness and focusing on readability and vocabulary usage. General studies on learning and how they apply to textbooks are presented in the Theoretical Background and Results sections later in this article.

Two studies examined the glossaries of 10 introductory-level college textbooks, in either psychology or geology (Zechmeister and Zechmeister, 2000; Kortz and Caulkins, 2015), and both identified over 2,500 unique terms. There was minimal overlap of terms in glossaries between the textbooks, with only a few of the total terms appearing in the glossaries of all 10 (less than 3% in psychology and less than 2% in geology). Their results indicate that glossary terms do not necessarily represent a consensus of essential terms.

Another set of studies examined discipline-specific terminology (called technical vocabulary) used throughout a textbook, beyond what is included in the glossaries (Chung and Nation, 2003; Chung and Nation, 2004). The technical vocabulary can be divided into two parts: (1) words that are not likely known or used in general language (e.g. glossary words such as metamorphic, felsic, syncline, and alluvial), and (2) words with a meaning related to the field but are also used in general language, often with a different meaning (e.g. bedding, transportation, intrusion, and meandering; Chung and Nation, 2004). This second type of terminology is particularly difficult for students because they need to recognize that the word is classified as a technical word, and they need to learn its meaning. Students with poor reading comprehension have an especially difficult time inferring the meaning of vocabulary items from context (Cain et al., 2004). In a college-level anatomy textbook, Chung and Nation (2003) identified one-third of the words as terminology, with one-third of those terms having a use and meaning outside of anatomy.

Edgcomb et al. (2015) examined how aggressive minimization of the number of words in a textbook affected student learning. They found that students learned more from and spent more time reading a passage of text with 211 words that covered the same concepts and examples as a passage with 1,255 words. Their conclusion is "not that materials should be watered down, but rather that great attention should be paid to using minimal text while teaching the same core topics" (Edgcomb et al., 2015).

A textbook with a reading level above that of a student may hinder learning. Hippensteel (2015) examined the reading level of two commonly used introductory geology textbooks and found that, on a scale in which a first year college student would be expected to have a reading level of

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13.0, the two introductory geology textbooks analyzed had reading levels of 11.0 and 13.4. Therefore, these textbooks are at an appropriate level for well-prepared college students but may be too challenging for those who are less fluent with written English.

Overall, this prior research of college-level textbooks, including geology textbooks, indicates that there are potential challenges for novice learners, both in terms of vocabulary and reading level.

Research Questions

This study has two parts. First, it establishes literature-based criteria for best practices on conveying information to novices through printed text. Second, it applies a subset of those criteria to introductory geology textbooks to determine how well they meet the criteria. Therefore, the research questions are:

1. What are recommendations for the most effective presentation of information to novice learners through printed text, specifically textbooks?
2. How well do introductory geology textbooks meet a subset of these recommendations?

RESEARCH DESIGN

Theoretical Background

The framework for the recommendations is guided by two learning theories based on cognitive science research on learning by actively constructing knowledge (Bransford et al., 2000). First, the cognitive load theory builds on the understanding that humans have a limited working memory capacity and can only attend to a relatively small number of pieces of information. Therefore, deep conceptual processing cannot occur if cognitive systems are overloaded with extraneous factors (Sweller et al., 1998; Mayer and Moreno, 2003). Second, the dual-coding theory proposes that humans have partially independent systems for processing pictorial and verbal material. Although each channel has its own limited cognitive load, using both channels together allows for deeper processing of information than each channel individually (Paivio, 1986; Mayer, 2003; Mayer and Moreno, 2003).

Novices, such as students, and experts, such as instructors, organize information differently as they are learning it (Chi et al., 1981; de Jong and Ferguson-Hessler, 1986; Kozma and Russell, 1997). Without an effective approach to organizing new information, novices can overload their cognitive processing, which prevents them from learning the important concepts (Mayer and Moreno, 2003; Cook 2006). Novices have more difficulties than experts in extracting the relevant information and seeing the big picture (Caillies et al., 2002; Patrick et al., 2005; Hegarty et al., 2010; Libarkin et al., 2010), which is a problem that experts may not recognize (Benson, 1997). As a result, instructional strategies that experts prefer may not work for novices, and strategies with support, or scaffolding, that are highly effective for novices may not be preferred by experts (Mayer and Gallini, 1990; Kalyuga et al., 1998; Kalyuga et al., 2003; Stofer, 2016). Textbooks are written by experts, but their design must consider the differences in how novices learn.

Placement of Authors in the Study

Authors Kortz and Smay were involved in the first part of the study, analyzing the literature to make recommendations for presenting printed information. Authors Kortz and Grenga were involved in the second part, examining textbooks in light of those recommendations. None of the authors wrote these textbooks; however, Kortz and Smay are currently authoring a new introductory textbook.

The "placement" of the authors in this study provides a "transparent exploration of why the study was conducted, how the researcher[s] fit into the study, and . . . context in which to address potential bias" (Feig, 2011, 6). To a certain extent, in this study the authors are researcher-observers (Feig, 2011), since they are collecting data passively through the examination of textbooks. However, they can also be considered action researchers (Feig, 2011) because the large-scale purpose of this research is to establish whether or not there is a need to use a new approach and create an introductory geology textbook that is better aligned with how novice students, including subpopulations of students with limited backgrounds in science, learn best.

Research Strategy

The first part of this study, Developing Recommendations, is a synthesis of research. The second part of this study, Analyzing Textbooks, is a descriptive study because it describes a current situation (Bishop-Clark and Dietz-Uhler, 2012). Although the aim is to answer research questions, this study is not testing predictions or identifying causal relationships. Instead, it is making observations of the current situation—of how introductory geology textbooks conform to learning theory—without influencing the textbooks.

PART 1: DEVELOPING RECOMMENDATIONS

Methods

In the first part of this study, the literature was surveyed for studies on how novices learn from information presented in printed form. Based on the findings, a list of recommendations on how to most effectively present written and visual information was created. The goal of this study is to provide an accessible foundation to those who are looking to improve the presentation of written and visual information to students via textbooks, lab manuals, and informational handouts. For more details and information, readers should refer to the original studies on which our recommendations are based.

Results

Research findings on specific aspects of how novices learn new information are presented, with references, in the first column of Table I. These research findings apply to figures and text presented independently, and also how they are used when presented together. For example, when text and figures are presented, students spend little time examining figures in text without a prompt, figures that are too complex and contain extraneous details make it difficult for students to extract relevant information, and an abundance of terms may impede conceptual learning. Table I includes all findings and references found in the literature search; a subset is used for the analysis and discussion in Part 2 of the study.

TABLE I: Synthesis of research findings on how novices learn, recommendations based on those research findings, and the criteria used to analyze textbooks based on these recommendations.

Recommendation	Literature-Based Research Findings	Recommendations for Designing Textbooks	Criteria Used to Analyze Current Textbooks
1	Students learn more when there is the dual-mode of text and images near each other (Mayer, 1989; Mayer, 2003; Mayer and Gallini, 1990; Harp and Mayer, 1997; Sweller et al., 1998; Carney and Levin, 2002; Mayer and Moreno, 2003; Cook, 2006).	Text and images should be combined on the same spread. A significant amount of text should be incorporated into or presented along with the figures.	• Whether citation in text and figure are on the same spread. • Percentages of text in figure text and regular text.
2	If unprompted, students tend to spend little time examining figures and look at them during breaks in the text (Busch, 2011).	Text should emphasize figures as appropriate and incorporate them at natural breaks in the text, such as the end versus the middle of a paragraph or section.	• Where citations to figures occur: middle or end of paragraph; middle or end of section.
3	Students have difficulty extracting relevant information from complex figures or pictures of geologic features, and they often focus on people or other irrelevant details (Patrick et al., 2005; Cook, 2006; Coyan et al., 2010; Hegarty et al., 2010; Libarkin et al., 2010; Stofer, 2016).	Students should be guided through figures with few extraneous details and cued to the important features; labeled sketches should be shown alongside complex geologic photos. Figures should be simple with few extraneous details.	
4	Figures, tables, and layouts should be designed using research on the way people perceive information (e.g., Gestalt principles) and streamlined to reduce cognitive load (Kosslyn, 1989; O'Donnell et al., 2002; Schnotz, 2002; Vekiri, 2002; Tversky, 2004; Van Dyke and White, 2004; Novick and Catley, 2007).	Artists and content experts should receive advice on creating figures, tables, and layouts, so cognitive design is emphasized over beauty and pizzazz (Evans et al., 1987).	
5	Students learn better when information is presented in short segments (Mayer and Moreno, 2003; Busch, 2011; Edgcomb et al., 2015).	Text should be separated into short sections, each focused on a single concept, rather than longer sections presenting multiple concepts. The total number of sections may increase, but the content will be more digestible because it will be concept based.	• Number of words in each section. • Number of paragraphs in each section.
6	When extraneous detail (distracting or "seductive" detail) is included, students have difficulties picking out the main concepts and often remember irrelevant information, even if the main ideas are highlighted (Reder and Anderson 1980; Reder and Anderson 1982; Mayer et al., 1996; Harp and Mayer, 1997; Harp and Mayer, 1998; Carney and Levin, 2002; Mayer, 2003; Mayer and Moreno, 2003; Edgcomb et al., 2015).	The content should include the essential concepts without distracting details.	

TABLE I: continued.

Recommendation	Literature-Based Research Findings	Recommendations for Designing Textbooks	Criteria Used to Analyze Current Textbooks
7	Students memorize terms without understanding the concepts they represent (Libarkin et al., 2005; Kortz, 2009; Clark et al., 2011), and a large number of terms may impede learning of concepts (Groves, 1995; Sweller et al., 1998; Kortz and Caulkins, 2015).	Text should focus on concepts with terminology minimized, as appropriate. Terms used should be carefully chosen and used consistently (Kortz and Caulkins, 2015).	• Percentage of words that are geologic terminology.
8	Misconceptions are often unknowingly perpetuated in figures or descriptions (Mikkilä-Erdmann, 2001; Watkins et al., 2004; Clark et al., 2011).	Misconceptions should be considered when drawing figures or writing text.	

In the second column of Table I, these research findings are applied to create recommendations for presenting printed information to novices, including integrating text and figures, guiding students through figures, and minimizing terminology without sacrificing rigor (see Table I for all recommendations). As previously described, these recommendations work together to maximize students' available cognitive capacity and encourage deep learning by facilitating integration of pictorial and verbal material.

PART 2: ANALYZING TEXTBOOKS

Methods

For the second part of this study, four textbooks (Marshak, 2008; Tarbuck and Lutgens, 2008; Plummer et al., 2011; Reynolds et al., 2013) with the largest market shares for introductory geology courses (Bill Minick, pers. comm., 8 May 2014) were analyzed. If textbooks had an essentials and a full version, the study included only the full version that was available to the authors at the time the study began. A preliminary analysis of the essentials version of one textbook (Tarbuck and Lutgens, 2008) indicated the sections studied were nearly identical, with the full version including one additional figure.

Since this study asks how well textbooks meet research recommendations, data from the textbooks are presented in aggregate where possible, without singling out individual textbooks. The Reynolds et al. (2013) textbook has an innovative format compared to the three other more traditional textbooks, as each chapter is divided into a series of two-page spreads in which the text and figures are intermingled together. The uniqueness of this design required modifying some analyses and/or reporting this textbook's results independently from the others.

The magma and igneous rocks chapter within all four textbooks was chosen for analysis in this study because the topic is usually covered in an introductory geology course, and it had fairly consistent coverage of subtopics between the textbooks. For some of the analysis, the entirety of the chapter was examined; however, for other elements, two correlated sections about magma formation and igneous rock formations were analyzed (Table II). These two topics were chosen because they were covered in all four textbooks, with one topic emphasizing processes and the other, descriptions.

Table I lists the criteria developed to analyze the textbooks based on the recommendations. Analyzing all recommendations is beyond the scope of a single paper, so the analysis focused on a subset of recommendations (1, 2, 5, and 7) that could be analyzed objectively, with as little bias as possible. These recommendations could be evaluated by looking at the textbooks (such as by counting words) and did not require expertise from design specialists nor additional investigations involving student participants.

The methods used to analyze the textbooks for each recommendation are described below. To ensure validity and reliability, the decision-making and iterative coding processes are described with examples given.

Recommendation 1: Integrate Text and Figures

Recommendation 1 involves two criteria. First, the entire chapter was examined to analyze whether the figure and its citation in the text were on the same spread. For each reference to a figure, it was noted whether or not it was on the same page or the facing page (i.e., a spread), thus determining whether students need to turn the page to examine the figure.

Second, the two categories (regular text and figure text) had to be operationally defined to analyze the percentage of words in figure text and regular text. Regular text was defined as words that were not part of a figure, including paragraphs and section titles. Figures included diagrams, graphs, and images, and three categories of figure text were defined: titles, captions, and labels (words on a figure or pointing to a part of a figure). Because of its unique format, Reynolds et al. (2013) featured a hybrid category in which text was displayed as short paragraphs (bullet points) related to specific figures. Bullet points were defined as their own category because they were interpreted to be a cross between traditional paragraph text and figure captions, as they clarified elements of figures but also tied in information related to the figures' conceptual contexts. They were set in a different font from the regular text, and they often began with a symbol or alphanumerical character, or had a leader-line to a figure.

Next, all words in the two correlated sections of each textbook were hand counted and placed into the regular text or figure text categories. Two authors established criteria for

TABLE II: Chapters and sections used in the analysis.

Textbook	Chapter	Magma Formation Section	Igneous Rock Formations Section
Marshak, 2008	Chapter 4. Up from the Inferno: Magma and Igneous Rock, pp. 96–117	4.2. Why Does Magma Form, and What Is it Made Of? (two sections: It's Hot Inside the Earth and Causes of Melting), pp. 99–101 4.6. Plate-Tectonic Context of Igneous Activity, pp. 113–115	4.4. How Do Extrusive and Intrusive Environments Differ? (one section: Intrusive Igneous Settings), pp. 104, 106–109
Tarbuck and Lutgens, 2008	Chapter 4. Magma, Igneous Rocks, and Intrusive Activity, pp. 108–135	Origin of Magma, pp. 120–122	Intrusive Igneous Activity, pp. 128–132
Plummer et al., 2011	Chapter 3. Igneous Rocks, Intrusive Activity, and the Origin of Igneous Rocks, pp. 54–81	How Magma Forms, pp. 70–71 Explaining Igneous Activity by Plate Tectonics, pp. 75–78	Intrusive Bodies, pp. 66–69
Reynolds et al., 2013	Chapter 5. Igneous Environments, pp. 106–137	5.5. How Do Rocks Melt?, pp. 116–117 5.9. How Does Magma Form Along Divergent Plate Boundaries, pp. 124–125 5.10. How Does Magma Form Along Convergent Plate Boundaries, pp. 126–127 5.11. How Is Magma Generated at Hot Spots and Other Sites Away from Plate Boundaries, pp. 128–129	5.12. How Do Large Magma Chambers Form and How Are They Expressed in Landscapes, pp. 130–131 5.13. How Are Small Intrusions Formed and Expressed in Landscapes, pp. 132–133

determining what would and would not be counted as a word. Nearly all of the text on the page was included in the word count, including numbers and mathematical symbols found within a sentence or figure. The following characters were excluded from the word counts: letters, numbers, or symbols that began a list or title; numbers that were within parentheses to reference a figure; numbers and symbols that labeled graph axes; and alphanumerical labels used for photo credits.

Recommendation 2: Include Figures at Appropriate Breaks

To analyze whether the references to figures appear at natural breaks, the entire chapter was examined. For each reference to a figure, it was noted whether the citation was in the middle or at the end of either a paragraph or a section.

Recommendation 5: Separate Text Into Short Sections

To analyze the length of the sections, all paragraphs and words in the two correlated sections in each textbook were counted as described above. For the three traditional textbooks, a section was defined as the regular text (not including figure text) between headings or subheadings. For Reynolds et al. (2013), a section was defined in two different ways, and two separate analyses were performed. The core of Recommendation 5 is that each short section should represent a single concept. For Reynolds et al. (2013), students could read each bullet point independently, as a separate concept, or they could read them in a series, analogous to a group of paragraphs between titles. Therefore, a section was first defined as a single block of regular text or bullet point. Second, a section was defined the same as for traditional textbooks, as a set of successive bullet points and regular text between two titles. These two conceptually different definitions of sections can likely be considered end-members of how students read the textbook.

Recommendation 7: Minimize Terminology and Emphasize Concepts

To analyze the amount of terminology used in text and figures, the percentage of words that have a specific geological meaning was tabulated, which first required a definition of what constitutes a geologic word. Words in a textbook consist of both words that have no relationship to minimal relationship to a specific discipline, and words that are part of its technical vocabulary, the terminology (Chung and Nation, 2004). Chung and Nation (2004) divided the terminology into two categories: words that are unique to the field and not used in everyday language (such as glossary words) and words that are used in general language, but also have a specific meaning to the discipline. In this study, these two categories, plus a third category defined by the authors as comprising general science and mathematical terms, were considered terminology, or geological words. Thus, all words were examined and put into four categories (Table III) similar to those created by Chung and Nation (2004) for analyzing technical vocabulary. Three of the categories included terminology and the fourth included all other words. Table III summarizes how each category was distinguished and gives examples of words in each group. Note that the geologic word analysis is based on the total number of words, not the number of terms (e.g., "divergent plate boundary" is three words).

Two authors discussed the categories and went through a paragraph of text together. Next, the authors identified a

TABLE III: Categories of geologic words (terminology).[1]

Category	Definition	Examples
Glossary words	Words found in the glossary of at least one of the introductory geology textbooks	Lithosphere, basalt, magma, batholith
Common words with specific geological meaning	Words that can be part of general or everyday language, but which have different meanings or nuances in geology. Includes words that have different scales when applied geologically compared to everyday life.	Massive, shallow, flow, shouldering, intrusion, wet, soft, steep, depth, hot, light, wall
Scientific or mathematical words	Words that are commonly used in the sciences, beyond just geology, and have a specific scientific meaning; often physical science or measurement terms.	Buoyant, mass, diffuse, kilometer

[1]Nongeologic words were defined as all other words not meeting these category definitions. Examples include: portion, support, perhaps, is.

set of 18 statements that represented a diversity of potential geologic words from each textbook and coded all words based on the four categories. Inconsistencies were discussed, and coding rules were created. Both authors then independently went through the two sections in one textbook and placed the words in categories. They noted discrepancies, discussed the categorization, and refined the coding rules. One author then used these rules to code words in the other three textbooks, highlighting words that were uncertain. The two authors again discussed the questionable terms and together placed them into categories, finalizing the categorization.

Common words with specific geological meaning were the most difficult words to categorize. To meet this category, the word could not be in the textbook glossary and the everyday use, as defined within English language dictionaries, had to be different than the meaning implied by the text (e.g., the general use definition of "massive" refers to size, but textbooks refer to it in the context of crystalline structure). This category also included words that have different descriptive measurement scales when applied geologically than when used in everyday contexts. For example, many students describe "shallow" as a depth one could reach by shoveling (Kortz and Murray, 2009). However, textbooks refer to "shallow" depths in the mantle; thus, the definition of what constitutes shallow depends on the context.

Results

Recommendation 1: Integrate Text and Figures

To analyze whether the reference in the text and figure were on the same spread, the total number of figures were counted (78, ranging from 17 to 29 per textbook) and the total references to figures were counted (173, ranging from 38 to 64 per textbook) in the three traditional textbooks. Reynolds et al. (2013) had 140 total figures but no traditional figure citations (e.g., "Figure 4.1" embedded in the text), since every figure is on the same spread as the relevant text. In the other three books, the figure and reference were on the same spread 67% of the time (ranging from 55% to 78%), meaning that students would need to turn the page to look at the figure when directed for one-third of the citations.

To analyze the percentage of words in figure text (titles, captions, labels) and regular text (titles, paragraphs), the total number of words were first counted, resulting in an average of 3,970 words (ranging from 2,894 to 6,009) within the two sections of all four textbooks. Excluding the Reynolds et al. (2013) textbook due to its integration of figures and text, figure text in the traditional textbooks accounted for an average of 23% (ranging from 20%–28%) of words, and the regular text (including titles) accounted for 77% (ranging from 72%–80%; Table IV). Figure text in Reynolds et al. (2013) accounted for 4% of words, regular text accounted for 35%, and the hybrid bullet points accounted for 61% of words.

Recommendation 2: Include Figures at Appropriate Breaks

To determine whether the figure citations within the text were at natural breaks, the number of citations to figures were first counted, as reported above, (173, ranging from 38–64 per textbook) in the three traditional textbooks. Figure citations were placed in the middle of a paragraph 83% (ranging from 79%–90%) of the time, and they were placed in the middle of a section 92% (ranging from 91%–95%) of the time.

Recommendation 5: Separate Text Into Short Sections

When the number of words in each section, defined as the regular text between headings or subheadings, were analyzed, an average of 195 words were counted per section (ranging from 185–203 words), with a total range of 44–472 words across 38 total sections in the three traditional textbooks; 38% of words were in sections made up of more than 350 words. There was an average of two paragraphs per section (ranging from one to six paragraphs) within the three textbooks.

The number of words in each section for Reynolds et al. (2013) varied depending on how sections were defined. When each hybrid bullet point was considered an individual section representing a different concept, the 28 regular text sections and the 87 bullet point sections together have an average of 48 words per section (ranging from 12–218 words). Alternatively, when the regular text and bullet points are considered to be paragraphs within a section bounded by headings, there were a total of 44 sections with an average of

TABLE IV: Total number and percentage of words in regular text and figure text.[1]

Totals	Average (Range of Textbooks)	Average Percentage of Total Words
Total words	3,290 (2,894–3,777)	n/a
Total in regular text	2,527 (2,270–3,016)	77
Titles	59 (42–76)	2
Paragraphs	2,468 (2,219–2,956)	75
Total in figure text	763 (624–904)	23
Title	32 (20–50)	1
Image	308 (201–412)	9
Caption	423 (403–442)	13

[1]These data are for three of the textbooks and exclude Reynolds et al. (2013).

124 words per section (ranging from 31–449 words). Regardless of the analysis method, Reynolds et al. (2013) has more sections but fewer average words per section than the traditional textbooks.

Recommendation 7: Minimize Terminology and Emphasize Concepts

When the percentage of words with a geological meaning were analyzed, an average of 31% of all words (ranging from 30%–33%) within the four textbook samples were identified as geological. Of the geologic words, glossary words were the most common, followed by common words with specific geological meaning, then scientific and mathematical words (Table V). In the three traditional textbooks, figure text had a higher percentage of geologic words compared to regular text (figure text: 43%, ranging from 41%–46%; regular text: 28%, ranging from 27%–30%). Figure text also had a higher proportion of glossary terms and a lower proportion of common words with a specific geological meaning.

DISCUSSION

The first part of this study created recommendations for designing printed text so it conforms to research findings on how novices' learning is affected by the content and design of text and figures (see Table I for the research findings and recommendations). Many of these recommendations can reduce students' cognitive load by reducing the amount of new information students must sort through and retain in order to learn new concepts. The second part of this study created and applied criteria to evaluate the extent to which four commonly used introductory geology textbooks follow a subset of these recommendations. Overall, textbooks vary in their alignment with different recommendations.

Recommendations 1 and 2: Integrate Text and Figures and Include Figures at Appropriate Breaks in Text

Research indicates that students learn more when text and figures are near each other, and students tend to examine figures when there are breaks in the text. Therefore, text and the related figures should be located on the same page, with a clear and intimate relationship between the two (Table I). This study's findings indicate that traditional textbooks are not in line with these recommendations. In the traditional textbooks, figures were connected to the text only by figure citations. Moreover, over three-quarters of the words are in the regular text rather than the figure text (titles, captions, and labels), suggesting figures have a secondary role. If figure citations are followed by the reader, 83% require interrupting the flow of a paragraph, and one-third require turning pages to examine the figure. Therefore, students are unlikely to look at figures when it would be most useful to them, thus decreasing the usefulness of dual coding between text and figures to understanding new content.

An exception to this observation is the Reynolds et al. (2013) textbook. This textbook incorporates many of the research findings about integrating text and figures. All the figures are on the same page as the relevant text, and over half of the words are in hybrid text linking the two.

Recommendation 5: Separate Text Into Short Sections

Research indicates that novices learn more when information is presented in short segments (Table I), but the findings of this study indicate that traditional textbooks include sections with a large number of words and more than one paragraph, suggesting that each section includes many details and more than one concept. Over one-third of the text is set in paragraphs longer than 350 words, which is roughly the length of a typed, double-spaced page. Therefore, traditional textbooks are likely not in line with this recommendation, since much of the information is not broken into segments that are easily digestible by novices, resulting in the likelihood of missing important concepts and details as they read.

Reynolds et al. (2013) is an exception in that most of the text is written in shorter blocks than traditionally found in textbooks. There were more sections in Reynolds et al. (2013) but fewer words per section, regardless of how sections were conceptually defined (either 48 or 124, compared to 195 for traditional textbooks). Since a content analysis was not conducted, this study cannot claim the textbook meets the essence of Recommendation 5 (i.e., short blocks focused on specific concepts), but the sections in Reynolds et al. (2013) contain fewer words than the other textbooks, and thus, this textbook meets an important part of the criteria for this recommendation.

Recommendation 7: Minimize Terminology and Emphasize Concepts

Geologic terms should be carefully chosen and minimally used, with emphasis placed on concepts (Table I). However, similar to an anatomy textbook (Chung and

Nation, 2003), this study found that one of every three words in the analyzed textbook sections were considered to be terminology, indicating that textbooks are not in line with this recommendation. If novices are exposed to a large number of specialized terms while learning the concepts they represent, this high percentage of geologic terminology will increase their cognitive load. Students are not just learning a new word, but the new concept signified by it. Therefore, this high percentage of geologic terms is likely a barrier for most students, especially those with lower reading comprehension (Cain et al., 2004).

Of the types of geological terminology, common words with specific geological meaning can cause particular problems for understanding of geologic topics because they may lead to misconceptions. Unlike glossary words, these words are less clearly defined and their geological meaning may not be apparent to novices. For example "wet crustal rocks" may cause students to envision cobbles with a coating of water, and "wall rock" may cause students to imagine a cliff perpendicular to the ground. In these cases, the meaning of the sentence changes if students do not have the same interpretation as geologists, possibly leading to misconceptions. In a similar way, the use of descriptive terms related to geologic time and spatial scale, such as "long" and "deep," can also lead to misconceptions because of students' deep-seated conceptual barriers (Kortz and Murray, 2009). Although not specifically investigated in this study, the abundance of common words with specific geological meaning may unknowingly cause misconceptions, as recognized in Recommendation 8.

In addition, the large amount of geologic terminology within figure text (over two-fifths of words) may negatively impact the advantages of dual coding between text and images because the verbal channel may become overloaded. Students may focus their attention on the terminology in the descriptions and labels, leaving little capacity to focus on and understand the concepts and processes depicted. Thus, the use of a large number of terms in figures is not consistent with the recommendation to use terminology in a way that promotes conceptual learning.

Specialized vocabulary is an important part of learning a scientific discipline, and this study does not recommend that terms are reduced to the extent that concepts are not adequately described or that students' scientific vocabulary is stunted. However, terms should be incorporated into the textbook, within both regular text and figure text, so that the emphasis is on learning concepts and the use of language supports learning. New terms should be used repeatedly, and text should avoid using a term only once, if possible. Deeper conceptual understanding is not substituted by memorization of new vocabulary words.

TABLE V: Average number and percentage of categories of geological words for all text, regular text, and figure text.

	All Text[1]		Regular Text[2]		Figure Text[2]	
	Average Number (Range of Textbooks)	Average of Percentage of Geological Words (Range)	Average Number (Range of Textbooks)	Average of Percentage of Geological Words (Range)	Average Number (Range of Textbooks)	Average of Percentage of Geological Words (Range)
All geological words	1,231 (868–1792)	–	717 (605–864)	–	327 (263–367)	–
Glossary words	965 (631–1,468)	78 (73–82)	533 (414–665)	74 (68–77)	265 (217–298)	81 (80–83)
Common words with specific geological meaning	193 (176–211)	16 (12–20)	143 (123–160)	20 (18–24)	44 (32–53)	13 (12–14)
Scientific or mathematical words	74 (57–113)	6 (5–7)	42 (39–46)	6 (5–8)	18 (14–25)	6 (4–7)

[1]Includes an analysis of words from Reynolds et al. (2013).
[2]Does not include an analysis of words from Reynolds et al. (2013).

Summary of Findings

Current textbooks have many excellent features, but few use a large variety of techniques derived from research to cognitively optimize student learning (Carney and Levin, 2002). In general, traditional textbooks are beautifully illustrated and comprehensively cover topics in text with separate figures, while using a large number of geoscience terms (described as "encyclopedic texts" by Bierman et al., 2006). Findings from the subset of recommendations analyzed in this study indicate that there is room for textbooks to become more aligned with research findings.

Melting rock and resulting magma composition

Magma forms when rock melts, and if a mafic composition rock melts completely, the resulting magma will also have a mafic composition. However, the composition of magma differs from the original rock if only some of the minerals in the original rock melt.

Different minerals have different temperatures at which they melt, and iron-free silicate minerals tend to melt at lower temperatures. If only the iron-free minerals in a mafic rock melt, then the iron-rich minerals remain solid and the resulting magma will be more felsic in composition. The idea that only part of the rock melts because minerals melt at different temperatures is called partial melting. Partial melting influences the composition of magma.

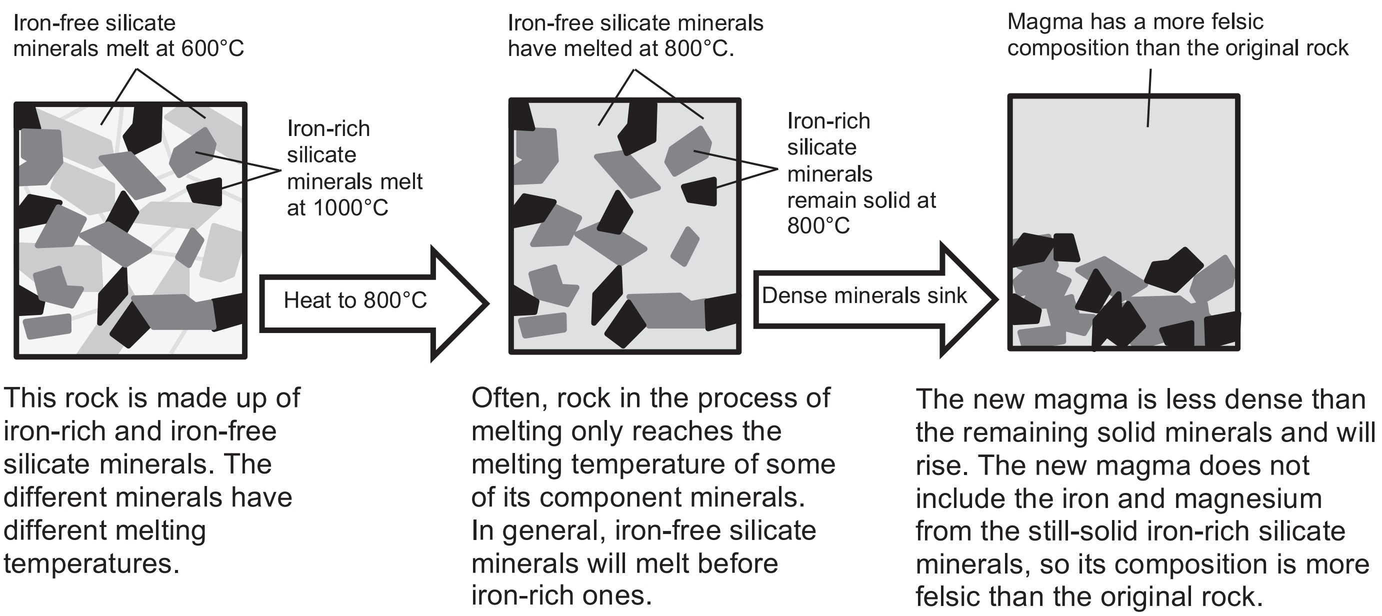

FIGURE 1: Example applying recommendations of this study.

Figures can be integrated with regular text, geological terms can be limited to the essentials, and text sections can be shortened with extraneous details eliminated.

Exploring Geology by Reynolds et al. (2013) is a geology textbook that breaks from tradition and incorporates many of the research-based recommendations. It combines regular text and the corresponding figures on the same pages (Recommendation 1) and directs students to focus on figures at appropriate times (Recommendation 2). The textbook has shorter sections of text than traditional textbooks (Recommendation 5). However, as with the other textbooks analyzed, it has a large number of glossary terms (Kortz and Caulkins, 2015), a similar percentage of geological terminology (Recommendation 7), and a large total number of words, indicating encyclopedic-style coverage of detailed information.

IMPLICATIONS

Analogous to research demonstrating that there are more effective techniques than lecture to maximize student learning in a classroom (e.g., Freeman et al., 2014), research also indicates that there are more effective techniques to present written curricula than traditional-style textbooks. Changing written curricula to conform to best practices is not making them less rigorous (e.g., Edgcomb et al., 2015). Instead, it helps present the concepts in a way that aligns with how students learn and opens new doors for independent study. Design informed by research may also increase the accessibility of the text to a broader range of students without sacrificing the content; for example, deliberate and purposeful use of vocabulary may help students with weaker reading comprehension better understand the concepts behind the terms (Cain et al., 2004).

A textbook more in line with how students learn would allow for more flexibility in instructional and learning practices. Encouraging reading through reading assignments and quizzes prior to classroom contact helps to enforce student learning (Heiner et al., 2014). Instructors would then have more time for interactive, student-centered classes, which increases student learning (e.g., Bransford et al., 2000; Freeman et al., 2014). Class time could focus on activities that require deeper-level thinking (i.e., analysis and synthesis), thus demonstrating that science is an active process of creating and applying knowledge.

Curricula developed or revised in alliance with this study's recommendations may also model to students how expert geologists understand the process of science. It has been suggested that an emphasis on learning scientific terminology may contribute to the misconception that science is a finished body of knowledge requiring memorization with little creativity (Groves, 1995).

In addition, reducing the number of terms in regular text and figure text could make the vocabulary less salient, which could shift student learning from memorization to learning concepts. For example, consider the following sentence:

> *"As an oceanic plate descends into the asthenosphere, volatiles are released into the overlying mantle wedge from the subducting slab of oceanic lithosphere, and the addition of water to the mantle rock causes the generation of magma."*

Instead, this sentence could be replaced with the following sentence that reduces the overall geologic vocabulary:

> *"As an oceanic plate subducts into the mantle, water is released from the subducting plate into the mantle rock above it, which causes the rock to melt."*

This new sentence conveys the same information, but it uses fewer geologic words (10 vs. 16), and of those words, fewer terms were used only once (20% vs. 75%, with words being combined if they shared the same root; for example, subducts and subducting). The second sentence helps to shift novice student learning to the concept instead of recalling terminology.

Geologists also value figures for communicating information, and emphasizing and integrating figures within regular text may help to indicate that value. Decreasing the amount of text overall and shifting the emphasis of text to focus on figures may help students develop valuable skills of interpreting visual information. Busch (2011) found that students who examined figures more frequently tended to learn more while reading text. Thus, redesigning curricula has the potential to foster visual literacy skills and enhance conceptual learning, supporting student development of geological expertise.

These recommendations can also be extended to presenting information in written form beyond textbooks. For example, instructors who develop their own handouts or introductions to geologic content for labs could use these recommendations to present information more effectively. Also, instructors and science communicators create informative handouts for students and the general public, and these recommendations may help increase their impact. Figure 1 is an example of how this study's recommendations can be used to create written content about magma formation. In this example, the text and images are integrated (Recommendation 1); figures are placed at the end of the related paragraph (Recommendation 2); figures are labeled, and they have an explanation beneath (Recommendation 3); text is separated into short sections with single concepts (Recommendation 5); the concept is presented without additional distracting details (Recommendation 6); and terminology is reduced by minimizing the number of geologic words used only once (e.g., other terms that could have been used include silica, granitic, basaltic, source rock, migrate) and by defining new terms after the concept is introduced (e.g., partial melting; Recommendation 7). Thus, it is possible to present information that maintains scientific rigor but is consistent with the recommendations on how students learn best.

LIMITATIONS AND FUTURE WORK

This study's analysis is limited, since half of the recommendations were analyzed using data from a single chapter of four textbooks. Although the chapters and sections were chosen to represent the textbooks as a whole, it is possible that they did not. The subset of recommendations evaluated were selected because the analysis provided rich but objective data; however, detailed analyses of the other recommendations would be helpful to produce a more complete understanding of current textbooks.

Although recommendations were made based on research on how students learn, this study did not test if following these recommendations increases learning from textbooks, and this is an important direction for future work. Mayer and Moreno (2003) summarized research results of 30 experiments that examined the effectiveness of theory-based strategies employed to reduce student cognitive load. These studies had effect sizes that ranged from 0.48 to 1.36, indicating large, significant learning gains by changing how information is presented. However, future work should be done to analyze student learning and attitudes in both the classroom environment and during independent learning activities in which a textbook is used, not just in a short experiment.

CONCLUSIONS

In conclusion, a set of recommendations was developed to align written curricula with research on how novice students most effectively learn new material. These recommendations are based on the ideas that students have limited capabilities for processing new information, and presenting information as text and figures together helps to increase those capabilities.

The results of this study indicate that textbooks already incorporate some of these recommendations, with Reynolds et al. (2013) incorporating the most, but all of the textbooks could be improved to better align with how students learn best. Based on this study's analysis, student learning through textbooks could be enhanced by placing figures and their corresponding text on the same page and visually connecting them, by breaking long sections of text into shorter segments with fewer words, and by reducing geological terminology and emphasizing concepts within both regular text and figures. Further research is needed to test the effect of the recommendations on student learning in a variety of environments.

Changes in how information is presented does not decrease its rigor but instead presents it in a way that may increase student's conceptual understanding. A potential implication is that students may be better able to learn fundamental concepts independently, such that class time can be devoted to applying knowledge and deepening conceptual understanding through interactive learning strategies.

A broader implication of this work is applying these recommendations to the design of printed materials for all novices, including the general public, and potentially improving science communication to a larger and more diverse audience. Moreover, it may be possible to reach audiences with barriers to learning science based on the way it is traditionally taught. Thus, learning about and changing how novices learn from printed text can create new pathways for diverse audiences to partake in scientific discourses, broadening both the scope and depth of scientific knowledge.

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