How Students Use Their Textbooks: Reading Models and Model Readers

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Textbooks have the potential to be powerful tools to help students develop an understanding of mathematics. However, many students don't regularly use their textbooks (Weinberg, Wiesner, Benesh & Boester, Submitted). The goal of this paper is to adapt two ideas from the field of reader-response criticism that can help us make sense of the ways undergraduate math students interact with their textbook; these two ideas are *reading models* and the *implied reader*. After describing these ideas generally and showing how they can be applied to the domain of mathematics texts, this paper will describe how they provide a new perspective on students' textbook use, and pedagogy and research related to textbooks.

Background: Textbook Tensions

While many students don't use their math textbook, those students who do use their textbook use it primarily when doing homework or studying for an exam instead of while preparing for class. Students claim that they are using the textbook to better understand the mathematics, but "neglect to use portions of the text in which the author attempts to develop that understanding" (Weinberg, Wiesner, Benesh & Boester, Submitted) by focusing on the worked examples instead of the chapter introduction or exposition.

When asked to explain why they don't typically read their textbook, undergraduate math students say that textbooks are difficult to understand, citing two reasons that are seemingly at odds with each other: they describe the text as being simultaneously "too chatty" and "too technical." For example, here are two excerpts from an interview with two calculus students:

> Interviewer: Are there some of those [parts of the textbook] that you look at more than others?

> Student 1: I think with the textbook I'm using now, I kind of skip to the definitions and the highlighted parts, especially if I'm in a hurry…. A lot of times I just feel like they're [the book] just kind of rambling or reiterating things.
>
> Interviewer: Do you think your books do a good job presenting—I'll call them the "big ideas" in the chapter? Or is it—one of you was talking about how sometimes they seem to ramble on a little bit and maybe aren't particularly clear at expressing those big ideas?
> Student 1: I feel like the big ideas are there, but when I start to break it down, sometimes the terminology or the wording they use, you can tell it makes perfect sense to them, I'm trying to decipher it and I have to read a few sentences over a couple of times in order to get it straight in my head
> Interviewer: Do they use a lot of precise mathematical terminology that gets in the way of things?
> Student 2: The way they derive certain things can be very technical... at different points. I assume it's very hard for someone who is writing a textbook and obviously knows the material to dumb it down to such an extent.

These examples highlight two tensions in students' perceptions and use of textbooks: the tension between understanding and examples, and the tension between colloquial and technical language (both of which students see as problematic). We can use reader-response criticism to better understand the source of these tensions.

Reader-Response Criticism

The theories of reader-response criticism originated as a response to traditional literary analysis, which views the meaning of a text as fixed and static. In contrast, Rosenblatt (1938) argued that the meaning of a text is constructed by readers through the reading process. The theories were more fully developed in the 1960's and 1970's through the work of critics such as Booth (1983), Fish (1976), Iser (1976), Jauß (1982) and Wolff (1971). The theories complement a constructivist perspective of learning, which posits that each learner actively constructs their own understanding through experience and reflection (cf. Steffe & Gale, 1995).

While literary criticism has a broad view of what constitutes a *text,* we will use this term to refer to a mathematics textbook, including its inscribed words, symbols, pictures, and tables as well as its formatting (such as margins, colors, etc.). A text is written by an *empirical author* (or a group of authors), who writes with the characteristics of an *intended reader*—such as a calculus student—in mind (Wolff, 1971). The student who reads the text is called the *empirical reader*. The text itself constructs an *implied reader* (Iser, 1976), which is a collection of behaviors, codes, and competencies required for a "proper understanding of the text" (Wilson, 1981, p 848).[1] The implied reader is different from an empirical reader, who has a physical existence. In addition, the implied and intended readers may not be identical because the author may not be fully aware of all of the codes that are embedded in the language of the text they write.

The Empirical Reader: Reading Models

In the same way that students' beliefs about mathematics affects the way they engage in mathematical problem solving (Schoenfeld, 1992), students' beliefs about the reading process affect the way they interact with the text. Students in many academic disciplines view the text as a vehicle for transmitting meaning, either that of the author or the meaning of the discipline itself (e.g. Lithner, 2003; Richardson, 2004; Wandersee, 1988). For example, a calculus textbook could be seen as a replica of "the ideas of calculus" or of the ideas of its author. Holding such a belief affects the way a student reads their book, making them more likely to replicate, transcribe, and imitate examples from the book (Richardson, 2004, p. 517) rather than engage with the text critically.

In contrast, a mathematician approaches a math text with skepticism about the validity of its arguments. She will appropriate (Bakhtin, 1986) the concepts, definitions, and theorems,

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[1] Jauß' (1982) reception theory posits that the empirical reader's construction of meaning is situated culturally and historically, which parallels the idea that learning mathematics is a situated activity (Lave & Wenger, 1991)

assess the value of each textual construct, and connect the new ideas she generates to her current understanding. A mathematician's reading of a text is personal, and they use the reading process as a springboard for generating meaning.

These systematic collections of beliefs that affect how a reader behaves as they read are called *reading models* (Schraw & Bruning, 1996, p. 301). The student's beliefs can be described as a *text-centered* reading model, casting the reader as a meaning-taker; the mathematician's beliefs can be described as a *reader-centered*[2] reading model in which the reader is a meaning-maker (Borasi & Siegel, 1990; Schraw & Bruning, 1999; Straw, 1990; Wittrock, 1984).

A reader who holds a text-centered reading model typically views their role in the reading process as forming an accurate mental copy of the author's or discipline's words and meaning; they view the text as containing a collection of static ideas and focus on replicating notation, vocabulary, and definitions. In contrast, a reader who holds a reader-centered model views the text as a springboard for generating new meaning and uses it to construct a personal understanding of the mathematics.

Reader-centered reading models are important because they may improve students' understanding of course content and motivation to learn. Schraw and Bruning (1996) found that psychology students who held reader-centered reading models tended to make more critical responses and were better able to recall propositions. When students demonstrated behavior consistent with a reader-centered model, such as summarizing, questioning, clarifying, and predicting, they were more successful in reading comprehension (Palinscar & Brown, 1984),

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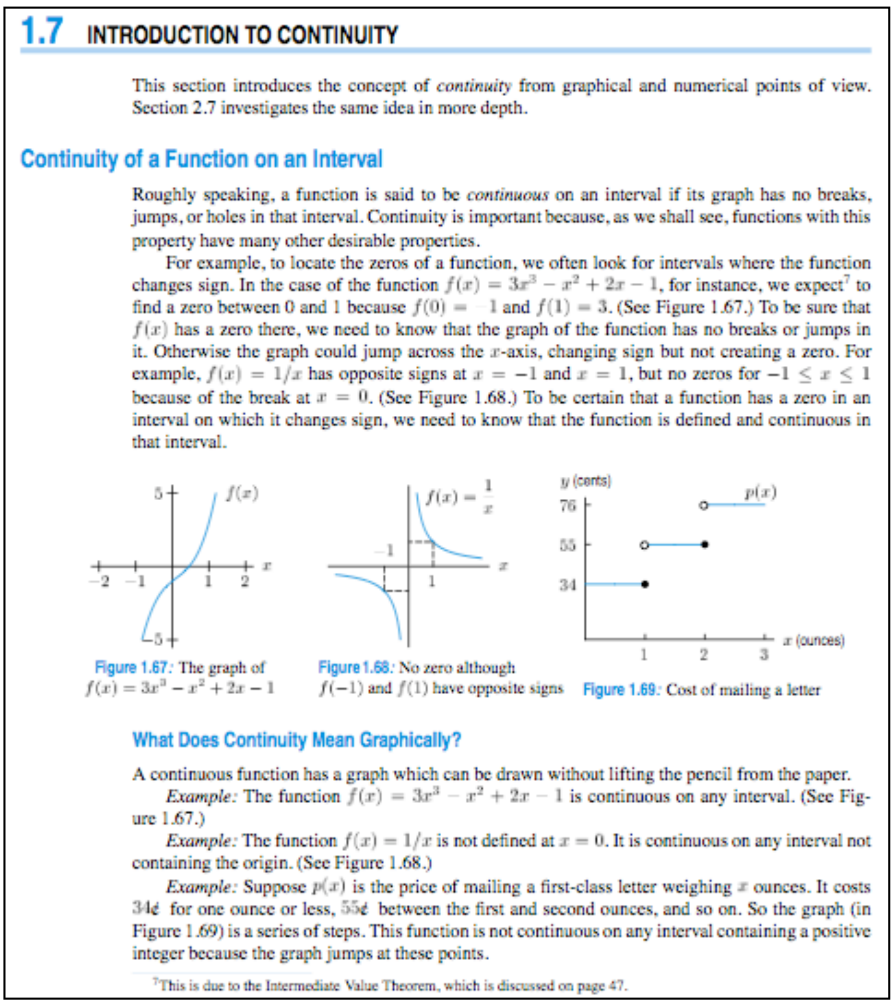
[2] There are three reading models described in the literature: transmission, translation, and transactional (cf. Schraw & Bruning, 1996). In the first two, the student's role is passive, so they have been combined into a "text-centered" model. To emphasize the focus on the reader, the transactional model is described here as "reader-centered."

solving and explaining science problems (Chi et. al., 1994, 1989), and learning new mathematical concepts (Weber, Brophy, & Lin, 2008).

The Implied Reader

While a reader's beliefs affect the way they read their textbook, the text itself plays an important role in the reading process. Specifically, every text constructs an *implied reader*. While the details of what precisely constitutes the implied reader have varied (Booth, 1983; Iser, 1976; Nelles, 1997; Wilson, 1981), we will view the implied reader as the set of behaviors, competencies, and codes that are required for the reader to read meaningfully and accurately. We will use an excerpt from a popular calculus textbook (Figure 1) to illustrate these three concepts.



1.7 INTRODUCTION TO CONTINUITY

This section introduces the concept of *continuity* from graphical and numerical points of view. Section 2.7 investigates the same idea in more depth.

Continuity of a Function on an Interval

Roughly speaking, a function is said to be *continuous* on an interval if its graph has no breaks, jumps, or holes in that interval. Continuity is important because, as we shall see, functions with this property have many other desirable properties.

For example, to locate the zeros of a function, we often look for intervals where the function changes sign. In the case of the function $f(x) = 3x^3 - x^2 + 2x - 1$, for instance, we expect[7] to find a zero between 0 and 1 because $f(0) = -1$ and $f(1) = 3$. (See Figure 1.67.) To be sure that $f(x)$ has a zero there, we need to know that the graph of the function has no breaks or jumps in it. Otherwise the graph could jump across the x-axis, changing sign but not creating a zero. For example, $f(x) = 1/x$ has opposite signs at $x = -1$ and $x = 1$, but no zeros for $-1 \leq x \leq 1$ because of the break at $x = 0$. (See Figure 1.68.) To be certain that a function has a zero in an interval on which it changes sign, we need to know that the function is defined and continuous in that interval.

Figure 1.67: The graph of $f(x) = 3x^3 - x^2 + 2x - 1$

Figure 1.68: No zero although $f(-1)$ and $f(1)$ have opposite signs

Figure 1.69: Cost of mailing a letter

What Does Continuity Mean Graphically?

A continuous function has a graph which can be drawn without lifting the pencil from the paper.

Example: The function $f(x) = 3x^3 - x^2 + 2x - 1$ is continuous on any interval. (See Figure 1.67.)

Example: The function $f(x) = 1/x$ is not defined at $x = 0$. It is continuous on any interval not containing the origin. (See Figure 1.68.)

Example: Suppose $p(x)$ is the price of mailing a first-class letter weighing x ounces. It costs 34¢ for one ounce or less, 55¢ between the first and second ounces, and so on. So the graph (in Figure 1.69) is a series of steps. This function is not continuous on any interval containing a positive integer because the graph jumps at these points.

[7] This is due to the Intermediate Value Theorem, which is discussed on page 47.

Figure 1: Excerpt from Hughes-Hallett et. al. (2004)

Behaviors

A behavior is a sequence of actions (either physical or mental) the reader performs while reading the text. Behaviors may be different for the intended reader than for the implied reader. It is not uncommon for textbook authors to explicitly describe how they want students to read their book. For example, Crauder, Evans, and Noell (2003) note: “It is not sufficient simply to read the examples in the text. Rather, you should work through each example yourself as it is presented” (p. X). Although the author may believe these are helpful behaviors (i.e. they are part of the intended reader), the required behaviors of the implied reader are dictated by the text itself.

This excerpt is section “1.7”, which follows sections 1.1 through 1.6. The ideas and vocabulary described in this section build on, and connect to, ideas that appear in earlier sections. In addition, the ideas presented in this section build upon each other; for example, the section that describes the graphical meaning of continuity is meant to be a specific aspect of the general description of continuity at the beginning of the excerpt. This implies that a reader needs to read linearly, following the order in which sections are presented without skipping parts of the text.

There are three graphical examples presented in this excerpt. They are each referenced twice on the page, and are meant to illustrate aspects of continuity. The inclusion of these examples suggests that readers are meant to create examples on their own to illustrate abstract ideas as they read. The reader is most likely required to connect these examples back to the original ideas and attempt to create generalizations or abstractions based on specific, common features of the examples. Furthermore, since these examples are referenced twice, the reader needs to make connections between the multiple instantiations.

Codes

A code is a “system of signification” (Eco, 1979, p. 8). It allows us to interpret and ascribe meaning to a collection of symbols. Codes rarely rely on explicit cues; rather, they are implicitly constructed by both the text and the social and historical structures in which the text is read. This paper will focus on two types of codes: those that allow the reader to interpret the formatting and structure of the symbols, and those that allow the reader to interpret the words and symbols themselves. Before exploring some of the codes that are required to read the calculus excerpt, it will be helpful to look at two non-mathematical examples.

In a film, a “jump cut” is an edited sequence in which the camera is moved without giving the viewer cues to establish spatial and temporal continuity. For example, Figure 2 shows two sequential frames from a film (de Beauregard & Goddard, 1960). A viewer who is accustomed to traditional continuity editing may have difficulty interpreting what is happening to the plot or characters in the film. However, a modern film viewer has a code that enables him or her to interpret the jump cut as a way of indicating movement in space and/or time. This is an example of a code that allows the reader to interpret the “formatting” of the film, as opposed to interpreting what they see or hear in each image or sound.

Figure 2: A sequential frames from Breathless

The second example is adapted from Radford (2002), who cites an excerpt from *A Canticle for Leibowitz* (Miller, 1959). In a post-nuclear future, a monk finds a half-buried sign labeled: “Fallout Survival Shelter. Maximum Occupancy: 15.” (p. 17). A modern reader can interpret “fallout” as a consequence of a radioactive explosion, and can imagine the associated dangers (such as sickness and contamination) as well as the state of such a world, which is informed by the wealth of post-apocalyptic fiction (including this novel). In contrast, the monk in the story interpreted “a Fallout” as “half-salamander” and “half-incubus” (Ibid., p. 17). Although the monk views fallout as dangerous, it is a very different type of danger than in our interpretation. By using a different code for interpreting the word “fallout,” the monk creates a different kind of discourse about the situation.

To interpret the excerpt from the math textbook, we rely on several formatting codes. The headings that are in a large font and outside the regular margin of the text indicate that their text describes a significant topic or concept, and that the text immediately following the heading will provide an overview of the topic. The formatting of other heads allows us to impose a hierarchy on the related ideas. Formatting such as boldface or italics (such as “*continuous*” or “*Example*”) indicates that the reader should use the text to construct a definition of the italicized word or use the text surrounding the italicized word to construct a mental image of the concept. The formatting of the three graphs on the page—specifically, that they are horizontally adjacent—tells us that they are meant to be examples of the same concept. Other math textbooks use a host of formatting techniques that require specific codes to interpret meaningfully.

In addition to these formatting codes, the math text requires numerous codes to correctly interpret the words and symbols. We can use the first two sentences of the third paragraph as an example:

> For example, to locate the zeros of a function, we often look for intervals where the function changes sign. In the case of the function $f(x)=3x^3-x^2+2x-1$, for instance, we expect to find a zero between 0 and 1 because $f(0)=-1$ and $f(1)=3$.

While we normally “locate” physical objects spatially, in this context the reader needs to interpret this as finding values in the domain; the reader may do this by imagining Euclidean axes to create a physical space in which to "find" these metaphorical objects. Writing the word "zero" instead of "0" tells the reader that "zero" is qualitatively different from the number zero; it is a characteristic of a function, and the reader needs to interpret this as describing values in the function's range (so that "zero" can be "between 0 and 1"). While this text has multiple authors, the "we" is meant to include the reader and its use suggests that the reader needs to participate in the activity that is being described. Similarly, writing "we often look" implies that the reader needs to create examples or mathematical candidates—in this case of an "interval" (which has a precise mathematical meaning). While an example of a function is given, the function itself does not "change"—rather the *output values* of the function change; in this case, the way they change— a "sign"—has a particular mathematical meaning that is different from a colloquial meaning. The phrase "in the case of" cues the reader to use the algebraically defined example to perform computations and use these as a specific example of the previously described abstract idea (such as in the supplied example of computing $f(0)$ and $f(1)$). The reader needs to interpret the notation "$f(x)$…" as a mathematical function and needs to interpret x as a varying quantity. Similarly, the equals sign is used here to define a function, as opposed to computing a value or indicating the equivalence of two expressions.

If a reader uses codes other than those required by the text, they will be unable to create a meaningful and correct interpretation. For example, Konior (1993) notes that proofs in textbooks contain delimiters that indicate when sections of a proof begin and end. The proof of a theorem may contain several inter-related arguments, and these are often indicated by specific language (in Konior's example, a sub-section of a proof is delimited by the phrases "We shall first prove that" and "We have thus proved formula (32)" (Ibid., p. 254)). These delimiters tell the reader that the included text is an argument that connects to other arguments in a particular way; if a student does not have the correct code, they will not be able to understand the proof's logical arguments.

Competencies

Once a reader has established the meaning of a part of a text, they need particular competencies to work within that context. For example, when a reader is using a topographic map (such as in Figure 3), they need to use a code to interpret the lines as representing a physical elevation. Once they are working within the context of elevation, they need various competencies to transform the elevation lines into meaningful information. For example, lines that are close together represent rapid changes in elevation (i.e. steep terrain) while lines that are further apart represent gradual elevation changes; consequently, a hiker would want to plan a route that generally follows the contour lines where they are further apart. Similarly, sharp "creases" in the lines represent places where a stream might form and, consequently, might be good candidates to find drinking water.

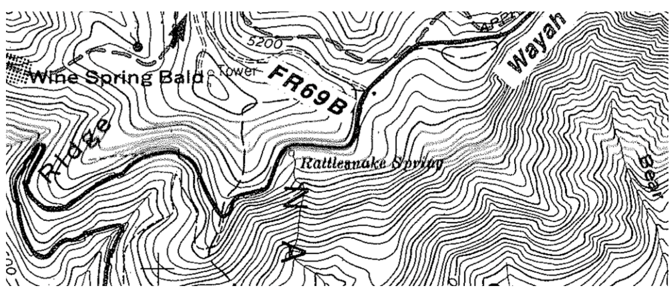


Figure 3: Topographic Map

In mathematical texts, competencies take the form of mathematical skills, knowledge, and understanding. In the excerpt above, the reader first uses codes to decide what mathematical context in which they are working—in this case, mathematical functions presented algebraically and graphically. Then, the reader needs particular competencies to understand what a function is (an association between "inputs" in the domain and "outputs" in the range), the ways it can be represented (algebraically, numerically, and graphically), and how these representations are connected. The reader needs to understand that "features" of a function typically refer to aspects of the range, must apply covariational reasoning (cf. Carlson, Jacobs, Coe, Larsen & Hsu, 2002) to understand how domain values affect range values, and must be able to perform computations using the various representations. Finally, the reader must understand aspects of "intervals" of numbers, the idea of the sign of a number and the "continuity" of Real numbers, and how these numbers are ordered with respect to a number line. Without these competencies, the reader will be unable to effectively analyze features of the algebraic function, understand the significance of "zeros," and relate this example back to the more abstract idea of continuity.

Reader Response Criticism as an Interpretive Tool

The ideas of reading models and the implied reader can help us make sense of the tensions described in the beginning of this article: that students find the expository text simultaneously too "chatty" and too "technical," and that they claim to read for "understanding" yet focus primarily on examples.

The implied reader constructed by a mathematics textbook follows particular behaviors. In particular, the reader needs to challenge and verify the statements and claims made in the text, make logical connections and inferences within the text, integrate new knowledge into their current knowledge base, determine the value of statements and concepts (e.g. using sectioning to identify the "big ideas"), generate examples of abstract concepts, generalize properties of examples, and connect these abstractions back to the text. These behaviors require an active engagement with the text. If a student has a text-centered reading model, they will attempt to extract information from the text instead of reading generatively. As a result, they may attempt to work by identifying superficial similarities between problems they are solving and the text (Lithner, 2003), focusing on the worked examples instead of the explanations.

The implied reader also uses particular codes to interpret the text. In some textbooks, the authors use colloquial language that is distinct from what one might find in a formal mathematics text (e.g. describing “breaks, jumps, or holes” without explicitly defining these terms). However, the reader needs to interpret these non-mathematical words in a specific mathematical way and the students’ codes may not facilitate this interpretation; as a result, the students may see the text as “chatty” without supplying them with meaningful information. In addition, the colloquial language is still embedded in more precise mathematical language (e.g. using “the function changes sign”). If students don’t possess the appropriate mathematical codes, they may be unable to meaningfully interpret the text and see it as too “technical.”

In addition to behaviors and codes, the implied reader of a math textbook has particular mathematical competencies. Many of these competencies may be at a relatively advanced level (e.g. for understanding functions or covariation). There is no shortage of research that describes the ways in which students’ have difficulty developing these mathematical understandings. As a consequence, a student reading the textbook may have little recourse other than to use the parts of the text that are most accessible by attempting to appropriate the skills and procedures from worked examples.

Implications for Research and Instruction

In addition to providing a lens through which we can describe the ways in which students use their textbooks, reader-response criticism provides a new perspective on aspects of teaching and research.

A textbook can be a useful tool for learning mathematics, but reading a math text is not an easy skill to acquire (Konior 1993; Reiter 1998). Instructors play an important role in that they mediate students' interaction with the text (Luke, de Castell & Luke, 1989 p. 252). However, instructors often implicitly endorse a text-centered reading model by emphasizing the comprehension of vocabulary, syntax, and symbols of the text instead of an interactive, meaning-generating reading model (Borasi, Siegel, Fonzi & Smith, 1998). Instructors themselves may possess a text-centered reading model, which affects their planning strategies. For example, Mesa and Griffiths (2007) found that instructors often began planning for class by identifying problems they wanted students to solve and then working backward through the expository text to decide what to emphasize. By using the text to identify "similar surface properties" and mimicking procedures (Lithner, 2003 p. 35), students may be led to abandon sense-making (VanLehn, Jones, & Chi, 1991) and write nonsensical proofs (Weber, Brophy, & Lin, 2008). In contrast, instructors can help their students develop productive reading models and identify aspects of the implied reader of a text, then design instruction to support the active use of the textbook. While there are relatively few resources for doing this in mathematics, there has been more work done in the area of science education and other domains (e.g. Dole, Duffy, Roehler & Pearson, 1991; Ferguson-Hessler & Jong, 1990; Horak, 1985; Mallow, 1991; Pearson, Roehler, Dole & Duffy, 1992; Pressley, Johnson, Symons, McGoldrick, & Kurita, 1989; Yore, 2000; Wandersee, 1988).

Text-centered reading models also shape the questions researchers ask and the ways they interpret data. A significant body of research has focused on mathematical language and word-problem comprehension (Siegel, Borasi & Smith, 1989). In this research, students' success is equated with their ability to translate and extract information, using vocabulary and syntax as the key predictors of success (Ibid.; Borasi, Siegel, Fonzi & Smith, 1998); doing this constructs the text as something to be comprehended rather than a meaning-making tool and casts the student as a decoder of the text. The body of research on mathematics reading quizzes highlights the implicit effects of this reading model (e.g. Axtell and Turner, 2007; Boelkins, 2008; Boelkins & Ratliff, 2001; Frazier, 2008; Gold, 2008; Hibbard, 2008; Ratliff, 1998). In reading quizzes, students are asked to read the text and then recall facts or explain concepts that the text explained; this focuses on the transmission of mathematical content from the text to the student. In contrast, science education researchers have used reading *questions*, in which students *ask* questions about the reading instead of answering them (e.g. Henderson & Rosenthal, 2006). While reading quizzes can only highlight students' *mis*understandings, (Offerdahl, Baldwin, Elfring, Vierling & Ziegler, 2008), reading questions can empower students to attempt to construct new meaning from their own ideas by reading the text.

Future Directions

Reader-response criticism—specifically the ideas of implied readers and reading models—provides ideas that enable us to discuss how students use their textbook to learn mathematics. These ideas have not previously been applied to the use of technical mathematical texts[3]. In order to turn them into practical pedagogical and research tools, they need to undergo further development and elaboration.

A reader-centered reading model is important for interacting with the text meaningfully. In order to describe this model for a technical mathematical text, we need to develop a more detailed description of the reading habits of expert readers (such as mathematicians). Similarly, in order to help students develop productive beliefs about reading, we need to understand their

[3] There has been some research that describes using a reader-centered model with non-technical math texts (e.g. Borasi & Siegel, 1990).

current beliefs and develop a more detailed description of how somebody with a text-centered model reads a math text.

It is not difficult for an experienced, reflective reader to begin to identify the implied reader of a text—the behaviors, codes, and competencies that are required to understand the mathematical ideas. However, in order for teachers to understand ways that they can help their students use the text productively, it is essential to be able to systematically identify these characteristics. Consequently, we need to develop a framework that allows us to identify and describe the implied reader of a technical math text.

In addition to developing these descriptions and frameworks, it will be important to develop pedagogical tools that allow us to teach students how to use a math textbook as a learning tool, and to find ways to analyze the efficacy of these tools. Research into reading in other domains can suggest some promising avenues; the task of math education researchers will be to adapt these tools into robust methods for teaching and learning mathematics.

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