Quantitative Literacy across the Curriculum: Integrating Skills from English Composition, Mathematics, and the Substantive Disciplines

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Jane E. Miller, PhD

Professor, Institute for Health, Health Care Policy and Aging Research, Rutgers University, 30 College Avenue, New Brunswick NJ 08901; (732) 932-6730; fax: (732) 932-6872; jmiller@ifh.rutgers.edu

ABSTRACT

Quantitative literacy is an important proficiency that pertains to "word problems" from science, history, and other fields. Unfortunately, teaching how to solve such problems is often relegated to math courses alone. This paper shows how quantitative literacy also involves concepts and skills from English composition and the substantive disciplines. It outlines a systematic approach to writing the answers to word problems – a fundamental skill that applies to ongoing education, everyday life, and the workplace.

KEYWORDS: Curriculum and Instruction; Language Arts; Mathematics Education; Science Education; Social Science Education.

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INTRODUCTION

Writing about numbers is a common task for students from elementary school through graduate education, from writing about bean plant growth for a grade school science project, to characterizing population trends or economic patterns in history papers, , to reporting on sports, the weather, or current events in journalism. These applications can be thought of as "word problems" in which numeric facts or calculations are used to answer real-world questions. This type of task is a critical piece of quantitative literacy – the ability to apply mathematical reasoning and computations to address substantive issues from a wide range of fields. The ability to communicate quantitative ideas is reflected in curriculum standards from a variety of disciplines (e.g., National Committee on Science Education Standards and Assessment, 1996; National Council of Teachers of Mathematics, 2000). Too often, however, students spend little time learning to work with numbers in non-mathematics courses, leaving them with an inadequate mastery of quantitative literacy concepts and skills.

In books such as *Mathematics and Democracy: The Case for Quantitative Literacy* (2001) and *Achieving Quantitative Literacy: An Urgent Challenge for Higher Education* (2004; which includes a section on K-12 education), Steen and others writing for the National Council on Education and the Disciplines make a compelling argument for the importance of quantitative literacy in a variety of disciplines. They identify tasks related to citizenship, personal finance, personal health, management, and work as areas where understanding and expression of quantitative ideas is needed.

Others have demonstrated the consequences of innumeracy – the lack of quantitative literacy – in many topics and settings. Indeed, a small genre of literature has emerged on the subject, including John Allen Paulos' books *Innumeracy: Mathematical Illiteracy and its Consequences* (1996) and *A Mathematician Reads the Newspaper* (2001), A.K. Dewdney's *200% of Nothing: An Eye-Opening Tour through the Twists and Turns of Math Abuse and Innumeracy* (1993), and Joel Best's *Damned Lies and Statistics: Untangling Numbers from the Media, Politicians, and Activists* (2001). These books suggest that many people emerge from school ill-equipped to apply quantitative literacy skills to the kinds of questions central to functioning in modern society.

Joel Best's candidate for "the worst social statistic ever" (2001) is a good illustration of innumeracy. He cites the example of a college student who included the following sentence in a paper, hoping to catch the attention of his audience with an impressive statistic:

"Every year since 1950, the number of American children gunned down has doubled."

Struck by the implausibility of this statistic (which implies more than one billion children killed by guns in 1980 – more than four times the total U.S. population for that year!), Best tracked down the original statistic in a 1994 report by the Children's Defense Fund:

"The number of American children killed each year has doubled since 1950."

Clearly, the student author who paraphrased that sentence lacked basic comprehension of the numeric concepts involved because he failed to recognize the logical impossibility of the number implied by his wording. Moreover, he was unaware that in the course of rephrasing the original sentence, he had changed the value of the number implied by the calculation he described. The placement of the phrase "each [every] year" within the sentence makes a huge difference in the underlying formula relating the number of child gun deaths in 1994 to those in 1950. In other words, several problems contributed to the stunningly misleading statistic presented in the student's paper: 1) a lack of mathematical comprehension; 2) a failure to understand the real-world social context (population size, number of deaths) against which to check the plausibility of the implied mathematical solution; and 3) a lack of precision in writing. This example illustrates the multidisciplinary nature of quantitative literacy and the approaches needed to teach students how to read, understand, solve, and write about word problems.

Despite the fact that many of the examples come from other disciplines, unfortunately word problems *per se* are often relegated to math courses where the focus typically remains on the calculations involved, with little if any attention to effective communication of the results. A search of the literature reveals several books devoted specifically to teaching how to solve word problems, none of which address how to convey the meaning of the result in sentence form and in the context of the original substantive problem. For instance, in *Math Word Problems Demystified* (2004), Bluman breaks the process down into (1) understand the problem; (2) select a strategy; (3) carry out (implement) the strategy; and (4) evaluate the answer. Abramson's *Painless Word Problems* (2001) explains and demonstrates four analogous steps for solving a word problem: (1) read it; (2) plan it; (3) solve it; and (4) check it.

On a more theoretical level, *Word Problems: Research and Curriculum Reform* (Reed 1998) includes a chapter titled "Representing Solutions," which deals with generalizing a strategy for solving classes of word problems. This step addresses the kinds of issues encountered in Bluman's or Abramson's steps 2 and 3, but not communication of findings in the context of the topic at hand. In related work, Countryman (1992) has argued that writing about computational and logical processes is an effective way for students to enhance their mathematical comprehension. The process of identifying operations from words will lead students to describe the mathematical steps used to solve the problem, but not how to express the solution in words.

This paper argues that an additional step should be added to the process of solving word problems: Writing the answer in prose in ways that place it back in its original substantive context, thus bringing the word problem full circle. This step completes the process of obtaining a purely mathematical (numeric or equation-based) solution, complementing the "behind the scenes" work of identifying, conducting, and verifying the calculations. In other words, writing up the answers to word problems is a different and equally important task, shifting the focus to interpreting the results of those calculations and how they answer the underlying word problem, whether it is drawn from biology, economics, public health, or other substantive field.

QUANTITATIVE LITERACY ACROSS THE CURRICULUM

Despite repeated documentation of innumeracy in the general population, quantitative literacy is a neglected skill in most curricula. Resolving this problem involves contributions by faculty in each of the major academic departments. Figure 1 is a Venn diagram that illustrates how English composition, mathematics, and substantive disciplines such as science and history intersect to generate quantitative literacy, each contributing unique and important concepts and skills.

Figure 1 about here

Mathematics teaches computations such as subtraction, division, and elementary statistics; experience with mathematical reasoning; and practice working with units. English composition contributes several elements that are essential to communicating numeric values and patterns. Foremost are basic expository writing skills such as introducing a question, writing paragraphs to organize evidence, and summarizing conclusions based on that evidence. Also important is exposure and practice applying rich vocabulary and analogies, which furnish essential tools for helping readers sketch a mental image of the shape of a numeric pattern.

Finally, disciplines such as science, social science, or health provide concrete topics with which to practice quantitative literacy – issues to which numbers can be applied to help test hypotheses or document patterns. In the process of weaving a topic and associated numeric evidence into a narrative, students often come to a better understanding of the pertinent facts and concepts, whether trends in prices of consumer products, geographic patterns of population growth, or an inverse relationship between two variables in a science experiment.

The sections below include a variety of examples to illustrate how each of these disciplines can participate in teaching important aspects of quantitative literacy. A series of principles are given for effective presentation of numeric information, starting with writing a sentence to report one number and progressing to comparison of two or more numbers. These approaches can be used for short-answer questions such as those on the High School Proficiency Assessment (HSPA), and can also help reinforce skills and concepts mandated under No Child Left Behind. Subsequent sections explain and demonstrate how expository writing techniques apply to writing longer pieces to present and tie together several pieces of numeric evidence, which can enhance longer essays or responses to essay questions including those on Advanced Placement, SAT or GRE Writing exams. Taken together, these principles comprise a systematic, proactive approach to help students write more effectively about numbers.

These principles are demonstrated using a teaching device called "poor/better/best" to help make abstract ideas concrete. After introducing a general principle such as "set the context," it is illustrate with samples of ineffective writing annotated to point out weaknesses, followed by examples and explanations of improved presentation.

FUNDAMENTALS FOR WRITING ABOUT NUMBERS

<u>Reporting a single number</u>

The most basic skill for writing about numbers is reporting one number, which involves application of two fundamental principles that outline the essential components of a sentence or paragraph about numbers: 1) set the context, and 2) specify units.

Set the context

As in most narratives, whether fiction or nonfiction, an important part of writing about numbers is setting the context – conveying who, what, when, and where. Without "the W's" as they are known in journalism, a number is seen in isolation, rendering it difficult to interpret that number or to compare it with other values. In social science papers "who" usually specifies a demographic group such as children, Asians, or women. In a science experiment "who" can be thought of as representing experimental conditions such as different growing conditions for plants. "Where" might not pertain to experiments conducted in a laboratory setting, but would be relevant for ecological experiments (e.g., different climatic zones) or social science comparisons (e.g., different cities or countries). Each of the W's typically requires only a few words or a short phrase that often can be included in the topic sentence for a paragraph. “In Iran,” “over the past century,” and “at elevations above 5,000 feet” are few examples. In the body of the paragraph, the W’s for individual facts or comparisons can be easily incorporated into the sentence with the numbers, as shown in the examples below.

Specify units of measurement

The second fundamental component of a sentence involving numbers is information about the units in which the values are measured and reported. There are several aspects of units to convey. First is the *system of measurement,* such as whether height was measured in metric (e.g., centimeters) or British (e.g., inches) units. Second is the *level of aggregation* or *scale,* such as whether distance was measured in centimeters, meters, or kilometers. Third is the *unit of observation,* such as whether poverty rates were reported for individuals, families, or states. Information about units usually can be conveyed in a short phrase such as “family income ($1,000s)” or “concentration, parts per million.”

Taken together, these two principles provide a mental checklist for planning or evaluating a sentence that include a number: Include the pertinent W’s and the units of measurement.

<u>Poor</u>: “The height was 27.”

> <u>Comment</u>*: What is being measured? In what units?*

<u>Better</u>: “The plant measured 27 centimeters tall.”

> <u>Comment</u>*: This sentence mentions the concept (height of a plant) and units, but fails to convey which plant, when, or under what conditions the plant was measured.*

<u>Best</u>: “Two weeks after germinating, the plant that was watered daily was 27 centimeters tall.”

> <u>Comment</u>*: This sentence conveys what, when, who (the plant that was watered daily), and units.*

<u>Comparing two numbers</u>

Once students have mastered the art of reporting one number, the next step is learning to write sentences that compare two or more numbers. Two additional principles guide the formulation of sentences involving more than one number: 1) report <u>and</u> interpret the values; and 2) specify direction and magnitude of the pattern.

Report and interpret numeric values

As students present numeric evidence to document a pattern or test a hypothesis, they should both report the raw data and interpret the statistics. By *reporting* the numbers in the text, table or chart, students provide access to the raw data so readers can see where the calculations came from or compare the data with other values. By *interpreting* the meaning of the comparisons they convey how those data answer the original word problem behind their history essay or laboratory report. A handful of numbers can be reported and interpreted in the text. If many numbers are involved, a table should be used to report the detailed values, complemented by prose to state the question and interpret the numeric evidence, with reference to the associated table. See Miller (2004) for more on complementary use of text, tables, and charts; Miller (2006) for examples.

Although it is important to interpret numeric comparisons, it is also essential to report the numbers. If students *only* describe a percentage change, for example, they will have painted an incomplete picture. Suppose a report states that the number of gun-related homicides in the United States was 60% higher in 1994 than in 1985, but does not report the number of such homicides for either year. A 60% increase is consistent with many possible combinations: 10 and 16 homicides; or 1,000 and 1,600; or 100,000 and 160,000; for example. The first pair of numbers suggests a very low incidence of homicide, the last pair an extremely high value. Unless the absolute homicide levels themselves are mentioned, readers can’t determine whether the nation has nearly eradicated homicide or faces a huge homicide problem. Furthermore, they can’t compare homicide statistics from other times or places.

Specify direction and magnitude of an association

The next step involves conveying the direction and size of the difference between two values. In other words, *which value* is bigger (direction of the difference between values)? *How much* bigger (magnitude of the difference between values)? Suppose students are writing a lab report about a biology experiment comparing plants grown in compost to plants grown in un-enriched soil.

Poor: "On the first day after germinating, the plants grown in plain soil measured on averaged 0.3 cm. tall. On the second day after germinating, they averaged 1.7 cm… [Series of sentences each reporting the average height on each of 20 days.] On the first day after germinating, the plants grown in compost averaged 0.4 cm. [Series of sentences each reporting the average height of plants grown in compost for the same 20 time points.]"

Comment: By reporting a long series of individual statistics on the heights of plants over several different time points, the student leaves it to readers to do the math to figure out whether each set of plants is growing and how fast. All those sentences reporting numbers also obscure the overall pattern instead of answering whether growth is similar for plants grown in the two different media.

Poor version #2: "The two groups of plants grew at different rates."

Comment: This sentence errs in the opposite direction, providing a very general summary without specifying direction, magnitude, or any numeric evidence.

Better: "The plants that were fed compost grew faster than the plain-soil plants."

Comment: This version conveys direction but not magnitude. If the growth rates differ only trivially, the case for using compost would be much weaker than if they differ substantially.

Best: "The plants that were fed compost grew faster than those grown in plain soil, 17 centimeters (cm.) per week versus 13 cm. /week."

Comment: This variant includes direction, magnitude, context (the traits of the two groups of plants), and units.

Teachers in different disciplines each have something to offer to students learning to convey direction and magnitude of a pattern.

Calculations to express direction and magnitude

Not surprisingly, one way to express direction and magnitude is by using results of arithmetic computations such as subtraction, division, or percentage change to quantify the size of a difference between numeric values. Although these calculations are usually mastered in the elementary grades, many writers of all ages have difficulty writing about the numeric results. However, once students have mastered the above-mentioned concepts and skills, they can approach the task of writing up such results with the cumulative mental checklist for reporting and comparing numbers: Include the W's, units, direction, and magnitude. See also (Miller 2004, Chapter 5) for detailed guidelines and examples of how to write about different types of numeric comparisons, including level, rank, subtraction, division, and percentage change. More advanced types of calculations such as coefficients from multivariate regressions can also be described using these principles; see (Miller, 2005).

To observe how these principles help yield clear, straightforward sentences about subtraction and division, consider the following data from a fictional biology experiment: On the first day, the plants that were grown in compost were on average 0.7 cm. tall. On the third day, those plants were on average 3.8 cm. tall. Subtracting, we obtain 3.8 cm. – 0.7 cm. = 3.1 cm.

Poor: "When I subtracted I got 3.1."

Comment: This version focuses on explaining the computation. It is also completely divorced from the word problem, failing to specify the topic, W's, units, direction or magnitude.

Better: "The difference in average heights was 3.1."

Comment: This version conveys one concept (height) and the magnitude of the difference between two unnamed values, but is still missing the W's and direction of the difference.

Best: "The plants that were grown in compost grew on average 3.1 centimeters between the first and third days."

Comment: W's, units, direction, and magnitude all in one simple sentence.

If instead we divide the plant height on day 3 by that on day 1, we obtain 3.8 cm. /0.7 cm. = 5.43.

Poor: "The ratio was 5.43."

Poor version #2: "The numerator was 5.43 times the denominator."

Comment: Both of these versions present pure mathematical results out of the context of the topic, and rely on the jargon of computation rather than everyday phrasing that will help readers understand the meaning of the result.

Better: "The ratio of plant heights was 5.43."

Comment: This version mentions "what" (height), implies that two values are being compared, and reports the magnitude of the contrast. However, it doesn't identify whether the comparison is across time or across growing conditions, or the direction of the difference. It also retains unnecessary mathematical lingo about the calculation.

Best: "On the third day, the plants that were grown in compost were on average more than five times as tall as on the first day."

Comment: This sentence incorporates the W's, direction, and magnitude. The original units of measurement cancel in division, so the result is expressed in terms of multiples. No jargon related to the mathematical operation is used, nor is it needed.

Vocabulary to express direction and magnitude

Another valuable set of tools for characterizing the shape of a numeric relationship is typically taught in English courses: vocabulary, analogies, and metaphors. These approaches are less familiar to many people who write about numbers, but can substantially enhance the description of numeric patterns. They also provide an opportunity for students to integrate "SAT" or "GRE words" – sophisticated verbs, adverbs, and adjectives – into routine usage rather than simply memorizing them from flash cards. Consider the following sentences:

"Sales of fresh spinach plummeted after its linkage to an outbreak of *E coli* was reported in national newspapers."

Comment: The verb "plummeted" expresses both the direction (decrease) and magnitude (large and rapid) of the change in spinach sales.

"Plants fed compost grew rapidly over the course of the experiment, whereas those in plain soil grew more modestly."

Comment: The adverbs "rapidly" and "modestly" convey that the two sets of plants are growing at different rates – that the magnitude of change differs even though the direction of change is the same for both plants (both grew).

Vocabulary can also be used to convey substantive aspects of the topic. For example, the word "frigid" communicates both the topic (temperature) and the level (very low). Words such as "majority," "expensive," and "sparse" also convey both the subject matter and approximate numeric value. Analogies are very effective for painting a verbal picture of a pattern, using phrases such as "J-shaped," "bell-shaped," or – for younger students – "rainbow-" or "smile-shaped." Again, such practice will not only reinforce skills and concepts that students encounter on standardized tests, but will also help them write more compelling, precise descriptions of patterns in math, science, and social studies assignments.

The strongest descriptions of numeric patterns combine vocabulary or analogies with numeric information because those approaches reinforce one another and tap into different ways of explaining and visualizing patterns that will appeal to students with varied academic strengths and learning styles.

EXPOSITORY WRITING TECHNIQUES FOR ORGANIZING IDEAS

Although students have been told to include data in their political science essays or science lab reports, rarely have they been given much guidance about how to do so effectively. For instance, when asked to report numeric data in a lab report, they often include a data table but fail to interpret the numbers or explain how they relate to the hypothesis for the associated experiment. In a political science essay, they often simply include a chart showing voting patterns or political party affiliation without any explanation of the patterns or how they relate to the topic at hand. If they bother to write about the numeric values at all, students often include a "naked number" in a sentence without explaining why it is there or what it means. In each of these instances, they are writing only the underlying word problem, leaving it for readers to figure out for themselves how the numbers answer that question, which will not take them very far when they are required to conduct such tasks in the workplace or other real-world contexts.

To overcome these problems, students can be shown how to adapt the standard essay structure taught in expository writing classes to an essay or laboratory report that includes numeric evidence. Although the organization varies somewhat across formats, all of them include one or more introductory paragraphs that present the topic or question under study, evidentiary paragraphs that report and interpret facts and patterns related to that question, and a concluding paragraph or section that explains how the evidence collectively answers the question raised in the introduction.

Consistent with good essay writing techniques learned for non-quantitative writing, students should organize the body of the narrative into separate paragraphs, each of which deals with a single question or series of closely related questions. The topic sentence for each such paragraph should introduce the question to be addressed in that paragraph. In English composition courses, students learn to write essays with thesis statements followed by textual evidence in the form of specific quotations from *Huckleberry Finn* or other literary works. Likewise, they can be taught to write topic sentences followed by numeric evidence for analytic essays about historical population trends or relationships between two or more variables in a science laboratory report. In the evidentiary paragraphs, they should also refer to an accompanying table or chart that presents the full set of detailed numbers, using prose to describe the pattern and explain how it answers the question at hand.

For instance, a thorough discussion of gasoline prices in the United States might start with a paragraph on national trends over the past few decades. A second paragraph might discuss the variation in gasoline prices by region and whether those geographic patterns have been consistent across time. Additional paragraphs could compare gasoline prices in the United States with those in Europe and other countries, and how those prices are affecting costs of other goods, consumer behavior, and gasoline supply. As they move from one topic to another, students should use topic sentences to introduce the subject matter in each paragraph before reporting and interpreting the associated numeric evidence. Transition sentences can then be used to guide readers from one major point (and paragraph) to another rather than stringing all of the information into one undifferentiated block of text. See (Miller 2006) for additional examples of how to organize and describe numeric information in prose.

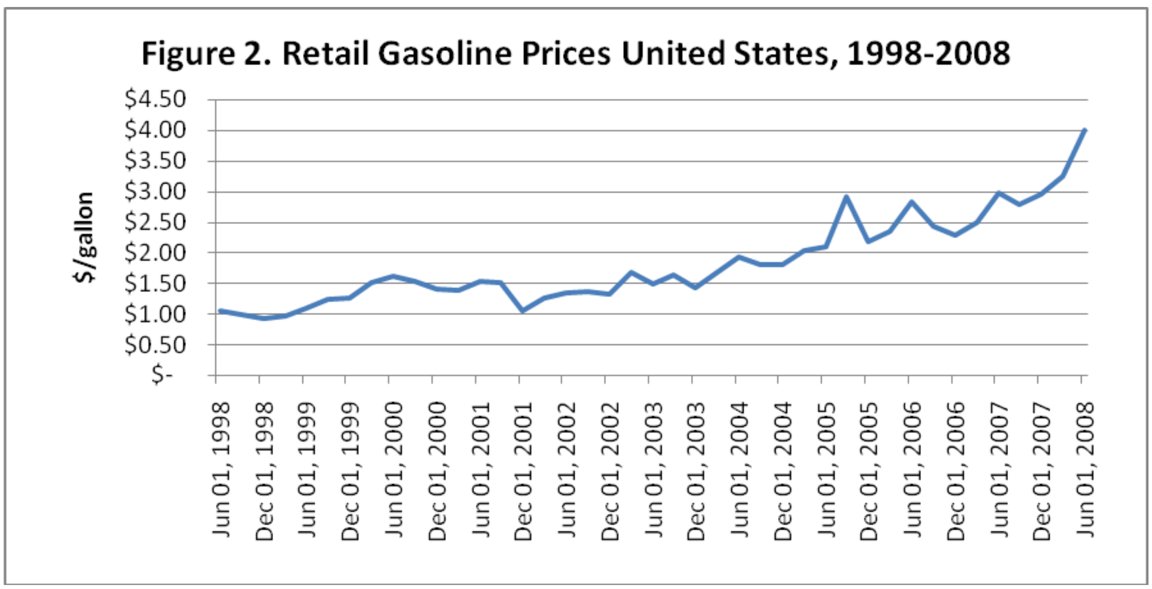
Table 1. Gasoline prices ($ per gallon) in the U.S. by region, 1998, 2003, and 2008

	June 1998	June 2003	June 2008
United States	$1.05	$1.48	$4.01
East Coast	$1.01	$1.44	$4.03
Midwest	$1.06	$1.51	$3.98
Gulf Coast	$1.00	$1.40	$3.94
Rocky Mountain	$1.16	$1.51	$3.99
West Coast	$1.16	$1.66	$4.24

Source: Energy Information Administration (2008)

Poor: "In June 2008, the price of gasoline topped $4.00 per gallon in the United States. Only ten years earlier, it cost just over $1.00 per gallon (Figure 2). Gas cost $0.20 more on the West Coast than in any other region of the U.S. (Table 1). In Europe gasoline is far more costly than in the United States. These costs affect costs of other goods because fuel is used in the production, storage, and shipping of many products.

Comment: This description simply lists statistics from several different tables and charts without explaining how they relate to one another or how the statistics fit together to yield a comprehensive picture of why gasoline prices are an important issue in the U.S. today. By lumping all of these issues into one paragraph with limited development of any one point, this description does not shed enough light on the distinct points to be made about time trends, regional differences within the U.S., international comparison, and so forth.



Source: Energy Information Administration (2008)

Better: [*Transition sentence from a paragraph describing national price trends to a paragraph describing regional patterns*.] "As shown in Figure 2, gasoline prices roughly quadrupled in the United States between June 1998 and June 2008. Table 1 examines whether this time trend occurred in every region, and provides information to compare prices by region. [*Additional sentences would report and interpret numeric evidence to quantify trends within regions and cross-region differences*.]"

Comment: By starting a new paragraph and section to present evidence on gasoline prices by geographic region, this version signals a second step in the investigation. The first sentence summarizes the conclusions of the preceding section (about average gasoline prices in the U.S.). The second sentence introduces a new dimension – region – to be considered in a further dissection of the national pattern with detailed numeric evidence reported from the associated table. Subheadings such as "Trends in gasoline prices," and "Variation in gasoline prices by region" could be used to provide further guidance through the different parts of the analysis.

SUMMARY

This paper has argued that quantitative literacy is a matter of concern for faculty and students in many fields – not just the math department! To communicate numeric facts and patterns effectively, students should be taught to draw upon concepts and skills from each of the major academic disciplines. Ideally, faculty will identify cross-disciplinary assignments, collaborating with colleagues in other departments to provide opportunities for students to learn and apply the complementary concepts and skills for quantitative literacy. By integrating expository writing approaches, mathematical calculations, and substantive topics from science, social studies, and other fields, students can learn to write clear, precise answers to word problems – a fundamental skill that will help them in the many numeric tasks they will face in throughout the rest of their education, everyday life, and the workplace.

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Figure 1. Contributions of major scholastic disciplines to quantitative literacy