How Do Secondary Science Texts Cover Mathematics and Engineering Principles and Design?[1]

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Abstract

Textbooks are the primary source of information for secondary teachers and students in learning science. We examined 13 new edition middle school and high school textbooks in earth science, life science, physical science, biology, chemistry and physics to determine how they addressed the following three research questions: 1. Do the science textbooks use science conceptual knowledge and mathematical applications to make applications and connections to society? 2. Do the science textbooks use the science and/or mathematical knowledge in technological applications? 3. Are any applications of engineering principles and design included in the laboratory activities and the problems and questions within and at the end of the chapters? Six older edition science textbooks were compared to the newer textbooks for length and use of mathematics. The results indicate that the newer texts do a good job in addressing questions one and two but fall short on question three. Furthermore, even though the older science textbooks are generally much shorter, they contain more applications and problems in mathematics.

I. Introduction

The overall goal of the recently developed *National Science Education Standards* (NSES)[1] and *Principles and Standards or School Mathematics* [2](PSSM) is to promote scientific and mathematical literacy, in all of our citizens. The standards include engineering and technology as important components of scientific and mathematical literacy. We examined the NSES in an earlier paper[3], and identified three major obstacles to their implementation, particularly regarding engineering and technology content:

1- Inadequate teacher preparation.
2- Discrepancies between state and national standards.
3- Inadequate grades 7-12 science and mathematics texts.

We have developed a course for high school teachers that demonstrates how the first obstacle can be overcome[4]. We have attempted to influence the state standards in Nevada so as to include more engineering and technology. This paper examines the third obstacle and suggests means of overcoming it. The paper addresses the application of science conceptual knowledge and

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mathematical skills to technological applications in general. We include any specific applications of engineering principles that appears in the activities, problems, and questions within and at the end of the chapters.

Some of the newest and most widely used high school science and mathematics texts are sampled and reviewed for their coverage of engineering and technology. We identify the problems with their coverage and suggest alternative ways of introducing engineering and technology to students. Throughout the paper we adopt science as inquiry as the preferred pedagogy for introducing engineering and technology to high school students.

I.1 Background

The literature demonstrates that science and mathematics textbooks have been examined for various components for years. Examples include but are not limited to the following: the presence of indigenous knowledge such as myths and legends, technology, the natural world, and social life[5]; the implementation of technology as a subject in junior secondary schools in the Netherlands[6]; assessment of the readability of secondary science textbooks[7,8]; sufficient evidence of applications beyond the textbook to explain difficult chemistry conceptual knowledge and to promote its rational acceptance by students[9]; examination of high school biology textbooks to determine whether evolution is a centrally organizing principal[10]; examination of secondary science textbooks for the vocabulary load or the total number of new science words introduced in the text[11]; examination of chemistry textbooks for difficult chemistry concepts[12]; analysis for the presence of the Science, Technology and Society (STS) philosophy in secondary science textbooks[13]; analysis of the coverage of plate tectonics in earth science textbooks[14] and last, the use of mathematics in secondary science textbooks[15]. This list, while not exhaustive, indicates that science textbooks have been examined for many attributes related to student learning and societal needs for a number of years. Still, in the many science textbook articles surveyed, although many include applications of technology, none address the presence of or need for applications and problems that address engineering principles and design.

II. Research Questions

The following research questions were used to judge the presence of technological and engineering applications and design in some of the newest and most widely used secondary science textbooks. These questions were chosen for their motivational potential and the possibilities they might offer to students to gain the kinds of problem solving skills needed for successful study and possible careers in technical fields. Mathematics was addressed in science textbooks because of the research that indicates that one reason for the high attrition rate in many engineering programs is related to inadequate preparation in mathematics prior to entering college[16].

1. Do the science textbooks use science conceptual knowledge and mathematical applications to make applications and connections to society?
2. Do the science textbooks use the science and/or mathematical knowledge in technological applications?
3. Are any applications of engineering principles and design included in the laboratory activities and the problems and questions within and at the end of the chapters?

II.1 Objectifying the Data

We designed a scale of 0-3 to indicate the degree to which each of the three questions was addressed in the textbooks we examined. Zero (0) indicates no presence, one (1) indicates some presence, two (2) indicates significant presence, and three (3) indicates substantial presence. We also provide some examples from the various textbooks that address the four questions. In the sequel, we use the following acronyms:

1. Science Conceptual Knowledge and Mathematics Applications to make Applications and Connections to Society (SCKMA/ACS).
2. Science and Mathematics Knowledge and Technological Applications (SMK/TA).
3. Applications of Engineering Principles and Design in laboratory Activities, Problems and Questions (AEPD/APQ).

II.2 The Textbook Samples

Secondary textbooks used in grades 6-12 science were analyzed for the information described in the above three research questions (See Table 1). The 13 newer textbooks were selected from some of the latest adoptions in science in two western states. The books were the latest editions of the publishers ranging from 1998-2000. Six older texts were also analyzed for total pages in the chapters and the degree of stress given to mathematics as compared to the newer books (See Table 2). We give one description of each of selected information in five of the six subjects represented by the textbooks.

Text – *Earth Science*, published in 1999 by Glencoe/McGraw Hill for middle school (grades 6-8) earth science. 705 chapter pages including all lab investigations.

SMKMA/ACS – This text has considerable content making science interesting and relevant to students following the Science, Technology and Society (STS) philosophy. It is difficult to classify information as impacting society or aligning more with technology since all technology has societal implications. Nevertheless, examples of information that impacts society, aside from how it uses technology, include but are not limited to: the discussion of various minerals and the extraction of their metals, e.g., gold, iron, copper, aluminum, etc. and their various uses in society including their use in industrial processes; minerals in paint pigments; gems for jewelry; concepts involved in mapmaking; and water erosion and deposition. The sections on environmental issues deal with the impact on society of environmental problems, often caused by technology, and the possibility of reducing some of the environmental problems through the use of new technologies. There is little application of mathematics to STS issues.

SMK/TA – The text has numerous examples of technology in society. However, at times this has little connection to concepts in earth science presented in the applicable chapters. Good applications of technology include human made building materials used in place of natural materials because of their greater strength, lower densities, and lower cost. The use of titanium for wheelchairs, hip replacements, planes, racing vehicles, etc. is mentioned. Chapter Four, Rocks, has a section on using co-generation to burn waste coal for electricity and heating. Regarding clean coal technologies, the mixing of limestone with coal to raise the pH and make the coal waste more environmentally benign is discussed. Chapter Five, Views of the Earth, has a section on remote sensing from space. Mapping uses of the GPS system and sonar are discussed.

AEPD/APQ – In addition to the regular experiments, each chapter has one activity where students design their own experiment. The chapters on earthquakes and volcanoes have technology inserts about predicting seismic activity and slowing mudflows caused by earthquakes. None of the lab activities or questions at the end of the chapter include word problems that required the use of mathematics for their solution.

Text – *Physical Science*, published in 1999 by Glencoe/McGraw Hill and designed for grades 8-9. 725 chapter pages with all laboratory investigations included.

Summary: In general, this physical science book includes the concepts and connections to technology and society expected in a middle school physical science textbook. What was unexpected is the weakness in the mathematics examples in the text and the lack of word problems with everyday examples in the chapter reviews. The investigations do have process skills that connect to engineering design and critical thinking.

Text – *BSCS Biology, An Ecological Approach*, 1998, Kendall/Hunt, 655 chapter pages with all laboratory investigations included.

SMKMA/ACS – "The Pioneers" section include technologies in biology. The "Biology Today" sections make a society connection with careers that need biology. The "Biology Today" section also includes problems caused by environmental degradation, food distribution and population growth. Famine in Africa, the carbon cycle and global warming, birth control, genetic screening, the cheetah on the way to extinction, cardiovascular diseases and biodiversity in danger, are all examples of the many topics that connected biology concepts to both society and technology. There are some mathematics problems that have STS applications.

SMK/TA – The laboratory work requires students to use sensors and probes in some of the experiments. The lab activities include many tables and graphs. A section of the book is devoted to the study of the effects of technology on ecosystems. One "Biology Today" section includes a topic on the technology of prenatal diagnosis and how ultrasound and amniocentesis are used to determine genetic defects. "The Pioneers" section includes the technology of mapping the human genome and bioremediation.

AEPD/APQ – The lab activities allow students free response in making observations. The discussion section requires close interaction with other lab groups. The discussion section also includes real world applications of the concepts studied in the lab. For Example, a lab dealing with the competition for resources between different species has this question: "A new FFR chain opens a restaurant one block from an established restaurant B. If the new one offers exactly the same menu and services as B, what do you think will happen and why? What does this suggest to you about the chances of a particular group of fish that swim up a river into a lake and attempts to establish itself?" Labs leave open the possibility for further investigations through redesign to incorporate different hypotheses with changes in variables. The population experiment with yeast is one such example. "Further Investigations" asks for a change in a variable such as temperature. Problems at the end of the chapters require students to make applications of the concepts studied in the chapters to real life situations. For example, "In making an extended journey into space, astronauts would have to take along a part of our biosphere. Design an efficient "package" of the biosphere for such a journey. Another example, "Choose a current environmental issue in the United States or in your local community. After some research, present to your class the causes of the problems and the potential solutions." The chapter endings also include an Applications section for students to apply the concepts in the chapter to everyday situations in their community. The Problems section also suggests other resources for information beyond the textbook.

Text – *Chemistry*, 2000, Prentice Hall, 881 chapter pages and a separate lab book.

SCKMA/ACS – The book attempts to make chemistry concepts obvious to students as a part of everyday life. The first chapter sets the stage by tying chemistry to materials, energy, medicine and biotechnology, agriculture, the environment, astronomy and space exploration and using the scientific method in problem solving. The connection of measurement to business is also given in the "Link" inserts that link chemistry to society.

SMK/TA – Each chapter contains a "Chemistry Serving" page that connects chemistry to society and technology, e. g. Chemistry Serving Industry describes and discusses the use of polymers to serve as better heat insulating materials for liquids. There are other Chemistry Serving inserts for the consumer (medicines from plants, systems of measurement), Chemistry Serving Society (Carbon-14 dating), Chemistry Serving (CS) the Consumer (chemical names on over the counter medicines), CS Environment (clean water and drinking water standards), CS Society (calculating the volume of air in air bags for cars). There are links for laser discs for more information on the topics presented.

AEPD/APQ – The end of chapter review sections include a part on alternative assessment where students use the scientific method to design and set up experiments that help them solve problems. One performance assessment is for students to design an experiment to measure the specific heat of several metals and compare the results to data in a reference book. There are many math problems with everyday applications. Each chapter also has a "CheMath" section that explains needed math skills and useful concepts and algorithms for solving problems in chemistry, e. g., (use of calculators, using positive and negative numbers, fractions, ratios and percents, converting units, making and interpreting graphs, solving an equation for one of its variables by isolating the variable, using constants and using logarithms. The lab book has good extension questions to apply the information to everyday life and suggestions for experiments to go beyond the information in the original lab. The basic labs are generally replication.

Text, *Physics;* Holt, Rinehart and Winston, 1999, 933 chapter pages including laboratory activities.

SCKMA/ACS – The book contains inserts titled "Consumer Focus" (shock absorbers and damped oscillation, holograms, microwave ovens, avoiding electrocution), and "Science, Technology Society" (Climatic warming, noise pollution, pollution and electric cars, nuclear waste disposal).

SMK/TA – The labs include the use of the Computer Based Laboratories (CBLs) technology and graphing calculators. The labs are quite traditional, generally verification of principles already studied, with little chance for inquiry or design on the part of the students. A number of inserts are included for "Tomorrow's Technology" (robotics, continuous flow heart pump, passive heating an cooling from the earth, deep sea air conditioning, solar thermal power systems and sulfur light bulbs, among others.

AEPD/APQ – The text contains a section called "Technology and Learning" that discussed the mathematics and technologies needed each chapter. For Example, the first chapter deals with using graphing calculators. The end of chapter review also has a section on "Alternative Assessment" that includes Performance Assessment and Portfolio Projects. There are many problems at the end each chapter and they include everyday phenomena such as sports, cars, planes, snowmobiles, spacecraft, sleds, etc. The questions at the end of each chapter also have a section on Conceptual Questions. These require some analysis and the application of a physics principle to solving a problem in an everyday event. For example, "Suppose the waste heat at a power plant is exhausted to a pond of water. Could the efficiency of the plant be increased by refrigerating the water in the pond?" In general, the lab investigations are rather traditional in that the students are not able to practice inquiry or engineering design principles in designing, setting up, testing, redesigning and eventually discussing results and conclusions.

III. Results

The survey of the latest texts yielded the results of Table 1. All the latest editions of the textbooks sampled include many examples of information that made science connections and application to society and some that connected mathematics, especially the chemistry and physics books. Thus, all provide a positive answer to Question 1.

In answer to Question 2, all textbooks have significant uses of science conceptual knowledge to technological applications. Unfortunately, none of the textbooks have significant mathematics use in technological applications except in the lab investigations in the chemistry and physics books.

In answer to Question 3, process skills needed to apply engineering principles and design are present in some of the laboratory activities and the problems and questions at the ends of the chapters. In some of the texts the presence of process skills is significant.

Table 1. Survey of Selected Current Secondary Science Textbooks.

Book	Publisher	Year	Grade/s	Pages	Q 1	Q 2	Q 3
Earth Sci	Glencoe	1999	6-8	705	3	2	1
Earth Sci	Holt	1998	8-9	663	3	2	1
Earth Sci	Holt	2001	6-8	566	3	2	2
Life Sci	Glencoe	1999	7-8	755	3	2	1
Life Sci	Holt	2001	7-8	635	3	2	2
Phy Sci	Glencoe	1999	8-9	725	3	2	1
Phy Sci	Holt	2001	8-9	595	3	2	1
BSCS Bio	Kendall	1998	10	655	3	2	2
Biology	Scott For	2000	10	941	3	2	2
Chemistry	Pren Hal	2000	11	881	3	2	2
Chemistry	Pren Hal	2000	11-12	1011	3	2	1
Con Phys	Scott For	1999	11-12	642	3	3	2
Physics	Holt	1999	11-12	933	3	3	1

Some older middle school (MS) or junior high school (JHS) (grades7-9) texts were also surveyed to determine changes in book length and emphasis on mathematics (See Table 2). The same numerical scale, 0-3 was used to indicate the degree to which each of the four questions was addressed as in Table 1 but with some changes. In this case, zero (0) indicates no difference, one (1) indicates more mathematics, two (2) indicates significantly more mathematics, and three (3) indicates substantially more mathematics. The mathematics comparisons are also made with equivalent books. In other words, the older earth science book is compared with a current edition of earth science, not a current edition of a physical or life science book.

In this comparison, we found that this sample of older texts are considerably shorter but include more mathematics in the lab activities as well as in the topics in the chapters.

Table 2. Survey of Selected Older MS/JHS Science Textbooks.

Book	Publisher	Year	Grade/s	Pages	Math
Interaction of Man & Biosphere	Rand McNally	1975	7-8	375	2
Interaction of Matter and Energy	Rand McNally	1973	8-9	341	1
Interaction of Earth and Time	Rand McNally	1972	8-9	373	1
Investigating the Earth	Houghton Mifflin	1987	9	513	3
Physical Science	Holt	1986	8-9	549	3
Physical Science	Prentice Hall	1984	8-9	475	1

IV. Alternative ways of introducing technology and engineering principles

The reviewed textbooks had a number of activities and student assignments that could apply to alternative ways of introducing technology and engineering principles even though the activities did not necessarily use technology. The process skills used in the alternative or design it yourself activities probably provide the best example of the kinds of skills used in technology and engineering principles. Such activities require students to come up with their own hypothesis for a problem, design a means for testing the hypothesis with the needed materials to carry it out, analyze the results of the designed procedure, reach some conclusions based on the results, communicate the results and conclusions with others and redesign and repeat the total process again if needed. Moreover, the end of chapter assignments that required students to extend science and mathematical concepts to everyday applications in society, e.g., principles learned in mechanics and body kinesthetic being applied to an understanding of robotics, would also fit within the rubric of technology and engineering principles. Still, all of the books could be strengthened by including additional activities in a Science to Technology or Science to Society section that actually requires students to use science and mathematics concepts in the construction of and testing of "tools," apparatus, etc. Examples of this that are sometimes found in older textbooks are bridge building, racecar construction, racing thread spools, paper airplane building, highway project design and packaging design. Students need to take abstract concepts and apply them to concrete situations, e.g., making things, if they are to remember and be able to apply science and mathematics concepts and skills to everyday situations. Much of this may be done in vocational education and technology education classes but often without the science and mathematics conceptual links and understanding.

V. Discussion and Conclusions

Based on our review of science textbooks, we conclude that all of the new books have sections that address technology and try to make connections to society. All of the newer textbooks have

CD backup, full motion laser videodiscs and web links for elaborations or extensions of topics. The chemistry and physics courses all make use of technology in the labs including computers, timers, sensors and probes. To some extent, they also address the process of technology design as called for in the NSES standards for Science and Technology for grades 5-8 and 9-12. Nevertheless, they fall short of the needed applications of engineering design and principles that should be included in the required activities and end of chapter problems and questions if students are to actually learn to apply science and mathematics conceptual knowledge to everyday applications in society. Furthermore, even though some of the textbooks are clearly better, when judged by our criteria, there is no guarantee that they will be adopted by even a majority of school districts. School districts have other considerations such as cost, delivery time, etc., that are part of the textbook selection decision aside from our preference criteria.

A glaring weakness of the Middle School science texts was the lack of mathematics both in the chapters and in the questions and problems at the ends of the chapters. Most problems at the ends of the chapters were multiple-choice, the way the standards will test students. What few word problems there were required little if any of even the most basic algebra where only one of three variable needs to be solved for. Inserting more word problems with applications to technology and society would seem to be one way of better preparing all students with the mathematics skills needed for high schools science courses such as chemistry and physics. Furthermore, it might help increase the pool of high school graduates who have the mathematics skills needed for technical career preparation in universities. On the one hand the absence of mathematics in the new texts is obvious, but at the same time the middle school science texts are including many more topics formerly only found in high school texts. But, student knowledge of this additional information, judging by the questions and problems at the ends of the chapters, is expected to be only descriptive, the what, with little understanding of the why or how. Part of the problem is certainly the knowledge explosion and textbook writers may be trying to put more and more of the new information into the new science textbooks.

The complaint of TIMSS[16] that textbooks are "a mile wide and inch deep" is certainly borne out in our survey of a limited number of late edition textbooks, especially when compared with the older books that contain the same basic conceptual information with more mathematics and generally far fewer pages. The new textbooks surveyed were 700-1000 pages in length but still did not include some critical material for our technical society. Authors need to make difficult decisions concerning what is important and must be included in science textbooks at each level.

Last, it is recognized that schools now must meet the needs of a much more heterogeneous group of students than ever before and tracking of students is discouraged. The lack of word problems in mathematics in MS science may be an indication of what textbook publishers feel is a need to make the reading level understandable to all. Furthermore, with the new science and mathematics standards, all students will now have to take some physical science in grades nine and ten in high school. Formerly, before the new science and mathematics standards, many students never got any chemistry or physics in high school unless they were in the college track. It will be interesting to see what kinds of integrated science textbooks are designed to meet the new two-year science sequence that must include the life, earth and physical sciences. These texts might be perfect for the infusion of engineering principles and design through the use of hands on activities in which students apply science and mathematics concepts as they construct “tools” that provide interest and relevance to the science curriculum.

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