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Teaching Materials for Cutting Edge Science

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TEACHING MATERIALS FOR CUTTING EDGE SCIENCE

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Abstract

This project addresses the lack in cutting edge science education in high schools in the United States, a gap which contributes to the decline of this nation's technological prowess. The existence of the gap itself is first demonstrated. Extensive background about textbook design paradigms is then discussed. This background is then applied to prototype lesson designs, intended to fill the gap between current available teaching materials and the most recent advances in science and technology.

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1. Introduction

The American media and frustrated parents have noted that the United States is no longer the model for science education in the world. Fewer students are interested in pursuing careers in the hard sciences and in engineering and technology. The National Science Foundation has shown in their *Science and Engineering Indicators* report that the number of degrees awarded in those fields declined from 1998 to 2002. Since then, the number of degrees has been slowly increasing, but they note that this is mostly due to international students studying here. Our nation has slowly been falling behind countries like Japan in our technological advances year to year, as evidenced by the formation of groups like the National Summit on Competitiveness, with the goal to "strengthen America's innovation capacity, particularly in science and technology research."

This issue of declining scientific capacity in the United States can be most appropriately addressed in the classroom. In particular, students develop an interest in science and engineering in their high school science classes. At the root of any science classroom around the country is the ubiquitous textbook, that tome of knowledge charged with bringing the scientific wisdom of all human history to our next generation. Unfortunately, science texts don't tend to address the most modern and exciting aspects of science and engineering. If a textbook chapter or set of materials were available to teach the cutting edge, meaning the advances in the last several years which have attracted the attention of both the scientific community and the media, then some students would likely become more interested in pursuing a scientific career.

I will examine the idea of the textbook in order to discover the intricacies of its workings. Textbooks do not simply exist. Textbooks are designed, and the elements of that design can be studied and understood. The process of gaining that understanding inevitably reveals weaknesses in the accepted system, trends in the history of the system, and improvements that could be made. This new knowledge allows the creation of a more accessible, more interesting, and more enlightening text.

Through examining current textbooks, I will demonstrate that there is currently a gap in our science education curriculum. The discussion of cutting edge science, primarily new discoveries and applications developed within the past several years, is severely lacking. The small amount of information that can be found in textbooks concerning the frontiers of science is presented in small examples and notes. The best that current books do is to devote a page per large chapter, or often less than a page, to discuss a small aspect of a new application. This discussion is lacking in substance and in any real teaching potential.

There are several different reasons for this lack of information about the cutting edge. The publication cycle of a textbook is fairly long, so the book has been finalized some amount of time before it is sent to the printer. Once the book is printed and distributed, it is often already a year or more out of date. Another reason is that text book publishers tend to stick with the same material as they update their books. High school science texts deal almost entirely in basic concepts of physics, chemistry, biology, and other sciences. These basic concepts do not change from year to year, so the updates that the publishers make are reasonably small. Much of the revision of a textbook deals with clarifying and improving previous content rather than creating a lot of new content about new parts of science.

Many of the revisions made in textbooks have to do with the presentation, and hence visual appearance, of the material. Publishers are always trying to find ways to improve their profits by creating books that are more attractive to teachers and school administrators. In general this means creating books that are better at teaching the material they are charged with disseminating, but occasionally changes are introduced to sell more instead of teach more. A brief history of textbook design will be created by examining books published from the 1950's through today. This analysis will demonstrate that there has been a distinct trend in textbook design throughout this time period.

This trend is that textbooks have been getting more and more visual as the years progress. Early textbooks were filled almost completely with text. As newer versions were released, textbooks started incorporating simple diagrams and drawings to help demonstrate their points. Later still more detailed sketches and black and white photography were included. As color publishing became more prolific, textbooks began including color diagrams and photographs, both to be clearer in describing the material and to be more attractive to potential buyers.

At the same time, textbooks began to move away from solid pages of text into more complicated layouts. Textbook designers began to chunk information into smaller pieces, allowing more section headings and small notes and tips. The most modern textbooks have taken this chunking trend and combined it with the growing use of diagrams and photographs to create visual displays of information that convey their information more effectively than simple text could before. The two separate entities of text and graphics have continued to meld into a more complete single method of visual design.

Unfortunately, this update in design techniques has not been accompanied by an effort to include new breakthroughs and discoveries in the text. This lack of materials seems to be the primary reason that at least an overview of cutting edge fields is not included in the science curriculum. An overview such as this would help to get children excited about entering modern science and engineering fields. I will show, through interviews with several working science teachers in various schools around the country, that teachers themselves would be excited to be able to teach some more cutting edge material.

While teachers are interested in teaching it, and they believe that students would be very receptive and excited about learning it, teachers believe they simply do not have the time to cover the newest advances in science in addition to the material required by their curriculums. These curriculums, however, are developed by the very teachers that are interested in having their kids learn about the frontiers. If materials such as textbooks, hands on projects, and assessment tools were readily available to help teachers teach the most modern lessons, then they have indicated that they would push to make an overview of the cutting edge a requirement in the curriculum. Once integrated into the curriculum, the teachers could make use of the excitement inherent in the discussion of new developments in science and engineering to better teach their students about the newest innovations.

The key starting element to begin along this path is a set of teaching materials. In this project I will develop such a set for teaching the basic concepts and applications of nanotechnology. My analysis of visual design trends and paradigms in textbooks will be incorporated into the development of these teaching tools. This knowledge will help me to create the most effective materials for both teachers and students.

In speaking with science teachers about the best and most exciting way to present material, it has emerged that practical applications serve both as good teaching aids and help to legitimize the study of the material in the minds of the students. My resource package will therefore use the actual modern applications of nanotechnology to help discuss and teach the main ideas and concepts forming the foundation of the science. Teachers have also mentioned that the best way to get students excited about a topic and allow them to absorb more is to let them do some of the discovery themselves. Therefore, in addition to written study material, I will develop a few fast teacher demonstrations and student experiments that will exemplify some of the main ideas under discussion. Finally, a small set of assessment materials will be developed so that teachers are able to evaluate the progress of their students.

2. Background

The current design of our education system has made the textbook an essential resource for teachers and students. As our knowledge of the world has increased throughout history the average citizen is required to know more each day to be considered an educated person. This array of knowledge is so vast that it is no longer always possible for an instructor to teach wholly from memory. The textbook serves as a repository of knowledge, as a reminder for the teacher and as a guide for the student. Textbooks are now viewed as essential resources, and as such have a very important role to play in education.

As with any essential technology, textbooks are constantly undergoing changes in both content and design philosophy. The content of a textbook is dictated primarily by breakthroughs in its associated field. The information presented in a basic high school chemistry book today may be very similar to that presented in books twenty years ago, but are certainly very different from anything that would have been published one hundred years ago. The fundamental principals of a field rarely change once the subject has become well established and understood, and it is the fundamental principles that are important in an introductory high school level text.

While the content in books may not change very often, ideas about how best to present and teach that content are far more volatile. In examining textbook design over the past several decades I have found that the vast majority of differences in the books are not content based, but are instead presentation based. While human interaction is one of the most ancient of concepts it cannot be as clearly defined as precise sciences such as physics. As such, textbook developers are constantly redesigning their books in an attempt to find the most effective way to interact effectively with their readers.

By far the most obvious change in recent years has been in the area of visual elements in textbooks. Each year textbooks include more and more photographs, diagrams, charts, and other graphic elements in their pages. Reasons for this include advances in publishing technology, a change in the literacy of the newest generation, and changes in fundamental concepts of education. This move toward the visual has been met with excitement or disgust from various parties in the education system.

Many teachers argue that the trend to include more visual materials in textbooks has reduced the quality of the material. They believe that the written word is a more precise descriptive tool and that graphics are mostly used as illustrations for simple aesthetic appeal. It seems, however, that the argument for the benefit of additional visual elements is stronger. Different messages and information are more readily adaptable to different media. Kress states in his book, *Reading Images,* that "not everything that can be realized in language can also be realized by means of images, or vice versa." When a textbook designer is trying to determine the best method for conveying a certain piece of information it is very beneficial to have the ability to choose between a written or graphical representation. Being able to use visual elements, instead of only text, allows the designer to choose the most appropriate means of representation, resulting in a stronger text overall. Kress also hinted at this idea, saying "it may be that visual representation is more apt to the stuff of science than language was."

Another important argument for the benefit of the visual turn is its potential for conciseness. There are many situations where a graphic will be able to deliver the main point of an argument in a far more efficient manner than a written description. An example of this is a large set of data indicating a particular trend. In a written description, if not all of the data is listed then at least some of it would likely have to be. The writer would then have to describe the trend in the data, attempting to indicate how strong the trend is or how varied it may be over time. If instead the author is free to use a diagram or line graph then the reader can almost immediately discern the traits of the data. Additionally, the trend would likely be able to be viewed in much more detail. The text could then be used to discuss the implications of the trend, rather than attempt a long description of the data itself. Kress addresses the same kind of idea, saying “the emphasis is not on sustained, concentrated analysis, but on the quick apprehension of facts and information.”

2.1 Textbook Analysis Methodology

The purpose of analyzing various science text books published over the last several decades was to determine if there is an actual trend toward a more visual textbook. The goal was also to determine the degree of the change if one was found. This analysis would support information found in research and interviews which indicated that there has been a very noticeable movement toward a more visual textbook.

The most basic of the factors in determining the degree of visual content in each book was a raw count of the number of graphic elements in the text. Graphic elements included any kind of picture, diagram, illustration, or other element that didn't consist purely of text. Tables were also counted, since they were a form of information design other than straight text, though tables were not included in the final count of graphic elements in the book. Individual graphic elements were identified by unique figure numbers in most cases, and when figure numbers were not used then graphics on the same page were counted as a single element unless it was very obvious that the elements were intended to be observed as separate.

The various books being analyzed had very varied page counts, so the raw number of graphic elements could not be used to fairly compare the different books. To remedy this issue, the number of graphics was divided by the total page count of the book to determine the average number of graphics per page. This number was a much more fair comparison between the different books, as it eliminated the difference in number of pages per book.

I also observed that the graphic elements in different books were of notably different sizes. Specifically, graphics in earlier books tended to be small diagrams, while graphics in more modern books were often large half page or full page graphics. Counting each of these graphics as equal visual elements in the books was not a reasonable comparison. I therefore decided to attempt to find the average page area devoted to graphics on each page of each book. To do this, I observed the average size of the graphics in the book and tried to determine the average percentage of the page that a normal graphic would cover for each book. I then used this estimate of the percentage of each page devoted to graphic elements and multiplied it by the average number of graphic elements per page to find the total average page area devoted to graphics in each book.

I also noticed while analyzing the books that the number of graphic elements changed depending on the section being observed. Specifically, pages devoted to problems for students to solve tended to have many small diagrams used to explain and illustrate the problems. Since these graphic elements tended to not be consistent with the use of graphics throughout the rest of the book I conducted their analysis separately and did not include the results in the average visual page area for the book. Similarly, appendices at the end of books tended to not have as many visual elements as the regular book chapters. Since the number and size of the appendices in each book was varied and did not necessarily correspond to the total number of pages in the book I decided to also remove these from the final calculation of visual page coverage. Removing both the problem sections and appendices from my general analysis seemed reasonable because I was most interested in the primary content segments of the book, and the sections omitted could be considered additional material that was not essential to the main instructional material.

In addition to the numerical analysis covered above, I also took notes on the types of graphics used in each book and the way that the graphics were used. This was important because the types of graphics varied greatly, from simple line drawings to full color photographs. Also, the way the graphics were used was also different in each book. Many earlier books tended to use a few small illustrations with very short captions to demonstrate some concepts in the chapter, while later books often used a combination of full color computer generated images and long descriptive text or callouts. It seemed that integrated text and complicated graphics could be deemed a more visual overall type of information design while the small graphics were obviously still being placed in a subordinate role.

The use of color graphics versus simple black and white images was also noted. Tied closely to the use of color was the overall quality of the graphics used in terms of clarity. Color was used more often in the more modern books. In terms of determining the overall visual orientation of a book, extensive use of color was viewed as a more visually oriented approach than the use of black and white graphics. This is because more information can be contained in a color image. Color also allowed illustrators to more clearly denote different elements in a single graphic, enabling enhanced clarity and understanding.

One of the most important aspects of the use of graphics in the books was the integration between the text and the graphics. This integration was also tied closely to the idea of content only being included in a graphic. In older books, graphics would always be used to illustrate a point in the text, and were often not necessarily required for understanding. In later books, information began to occasionally appear only in graphic elements and not necessarily appear at all in the actual text. This is made possible by the integration of text and graphics. With this integration the illustrations could be made to include long callouts and descriptions. Information in these descriptions was often not included in the actual text of the chapter

This distinction between using graphics to illustrate text points and using graphics to convey new information is very important. In the case where the graphics are simple and are tied closely to the text it is obvious that the graphics are subordinate to the information in the actual text. This gives the visual elements in the text an unimportant role. In contrast, when there is information presented in only the visual elements in the book it becomes clear that the graphics are considered important themselves. This distinction between unimportant and important graphics shows that textbook designers have been placing a much greater information load on their visual elements.

2.2 Evidence for the Visual Turn

The idea that textbooks have been getting more visually oriented with the passing years is not merely an illusion. This transformation is backed up through analysis of similar science textbooks published over the last several decades. Not only has the raw amount of graphics used in books increased, but the way that those graphics are used has changed as well. While earlier books relied on only a few black and white diagrams to help back up the information in their text, more modern textbooks rely on graphics a great deal when explaining concepts and giving examples to aid in understanding.

Principals in Optics, published in 1959, is a prime example of textbooks published in the late 50's and 60's. The book features 29 photographs and 308 drawings in total, averaging out to 0.47 images per page, or about one graphic element every two pages. Each of these individual graphics was rather small, so that there wasn't much page area devoted to visual material. After taking size into account, graphics accounted for about 9% of the total usable space on the page. Anyone who has used a more recent textbook will recognize that this is a very small portion of the page devoted to graphics.

Principals of Biochemistry, published in 1982, offers a good example of a book between those belonging to the previous generation of the 60's and the books of today. A total of 206 photographs and 353 drawings were included in the book, averaging out to 0.67 images per page, or about one graphic every page and a half. While this may not appear to be a big increase over books from the 1960's, the images used were larger than those used previously. After accounting for image size, 17% of the total page space was devoted to visual elements.

College Physics, published in 1995, is a modern example of books today. 279 Photographs and 576 illustrations were printed in this book, for a whopping average of 2.17 images per page. This is a drastic increase in the raw number of visual elements that are presented to the reader. The images in the book were, however, smaller than most of the ones found in previous decades. It seems that in designing the book the authors chose to use many illustrations to help show examples rather than using a single large illustration. The exception to this rule is a full page color photograph at the beginning of each chapter. After taking the smaller image sizes into account, the total page area for visual elements in the book was 32%. This is about three and a half times more visual content than was present in the books from the 1960s. Such a significant jump is certainly evidence that the use of visuals in textbooks has been on the rise.

Another major difference between the textbooks over the years was the use of color. Textbooks in the 1960s use no color at all, and print their photographs on special glossy paper that is bound together with the regular text. In Principals of Biochemistry from 1982 all of the photography was in black and white, though it was included with the regular text. In contrast, 70% of the drawings and diagrams used were in color. The use of color was very limited however, as the book only used one light shade of red and one light shade of green, making for a total of four colors that could be used: red, green, the black used for the text, and the background gray color of the pages. The most modern textbooks use color almost exclusively for their visual content. The only black and white images present in College Physics were 13 photographs, and most of these were portraits of scientists from the past. Modern textbooks make use of full color photos and diagrams, not limiting themselves to a small selection of colors.

While the raw numbers themselves indicate a shift toward visual content in textbooks, the most important difference to note between these textbooks of different eras is the way in which the graphics are actually used. The oldest of the textbooks makes it exceedingly obvious that the graphics were added as an afterthought to the text. The drawings and illustrations that are used to reinforce the points in the text are often of poor quality and are not nearly as informative as they could be. These small graphics are captioned by very short phrases only a few words long, so that the student must thoroughly read the text around the graphic in order to understand what the illustration is really trying to communicate. It was even more obvious that the few photographs that were included were not necessarily an integral part of the design but were instead added as an extra flair, most likely to appeal to those considering purchasing the books. All of the photographs are grouped onto special glossy paper scattered throughout the book so that one or two photographs are included every few chapters. Because of this segregation the photographs are not tied in well with the text, and the student often finds that the concepts that apply to the photos are discussed several pages away from the actual inclusion point in the photographs.

The middle era textbooks, those published in the 1980's, make much better use of their graphics in general. Captions for all of the graphic elements tend to be a sentence or two in length so that the student can understand the point of the graphic without having to read the rest of the text to discover its significance. The illustrations are much more complex and clear than those present in earlier texts, often due to the ability to use multiple colors to distinguish different parts of the diagrams. While the photography was all in black and white, it was included within the text so that it was more obvious that it was relevant to the concepts being discussed on the same page. It was evident that the graphic elements were actually being used to enhance the textbook's ability to communicate effectively instead of being present only to look nice.

Modern textbooks have taken one more step beyond this, including graphics that contain information that cannot be found in the text alone. The primary examples of this are the photographs that are frequently included in the margins as an example of the concepts being applied in real life. As an example, in a section of the physics book talking about friction, a photograph is included in the margin of a skier speeding down a snowy slope. The long caption for the picture talks about the materials that are used on the bottoms of skis to reduce the amount of friction between the skis and the snow. This additional information is not present in the rest of the text. In this case, the graphic element is being used by itself to communicate with the student. This role of the photograph is evidence that publishers are now willing to remove information from the text and delegate it only to the visual elements being used.

This progression of the role of graphics in the textbook, from infrequent photographs that are hardly relevant, to helpful diagrams and photos of the topics under discussion, and finally to primary information carriers that are important entirely on their own shows that there has been a drastic turn toward the visual. As textbooks have progressed not only have they included more visual elements per page, but they have also increased the importance of each of those elements. The integration of text and graphics has also become more prevalent with each passing decade, and entire paragraphs are now often used as captions or even included in the graphics themselves. This trend will likely continue in the future until the text and the graphics are entirely molded into a single paradigm of overall visual information design.

2.3 Reasons for the Visual Turn

This new turn in textbook design could not have begun without the aid of advances in the publishing field. Previous publishing technology made it very difficult to create much more than simple text in rows on the page. The development of powerful personal computers and software has been the key to more advanced design. Instead of mocking up textbook pages on physical paper and then sending these sheets to the printer, the textbook designer can now complete the process almost entirely on the computer. Text manipulation is now a breeze, with the computer able to recalculate line breaks, size changes, position changes, and more so quickly that the user can barely notice a lag. This agility gives the designer far more freedom to try new layouts and techniques in far less time. This allows him to create a much more pleasing and understandable page layout in less time than ever before.

One of the most powerful features of design software is its adeptness at handling images. A simple but essential advancement in textbook design was the use of color. Design software can handle the full range of colors available to the printer. Photographs and diagrams can be quickly and easily designed, reshaped, colored, and adjusted as necessary. The most important new development, however, is the ability to integrate text with these graphic elements. Designers are no longer limited to diagrams with captions that are referenced somewhere in the text. Instead, an entire page can be devoted to a large complex diagram with text not only for simple callouts but also presenting large chunks of information. It is common today to find information in visual sections which does not actually appear in the rest of the text in the book. The graphic has been identified as an educating entity of its own, rather than a simple subsidiary of the content presented in the text.

Printing technology has allowed the designers to take full advantage of their new graphic abilities. The most significant printing advance is the ability to use color fairly easily and inexpensively. While original color textbooks may only have used a few colors, and sparingly, printers today can recreate the full gamut of color. By integrating the printing systems with the design and graphics software the printers are able to create near perfect color duplicates of original source material, such as historic photographs or small color changes in chemical reactions. This technology in hardware and software has allowed designers the freedom to experiment and to create advanced education materials that are clearer, more concise, and more exciting to their students.

Students growing up today develop a different kind of literacy than those growing up in an era before advanced color printing, color television, and the multimedia internet. Pamphlets, newspapers, and books, until relatively recently, used to be page after page of black text on white paper. That view has changed drastically. Magazines that young people read today are stuffed with full page color advertisements, large photographs, and detailed diagrams. While science reporting had long been limited to the realm of text with small charts or black and white photographs, technology has greatly widened the envelope of creativity for these reporters. A popular example of this change can be seen in Scientific American.

Increasingly as years go by Scientific American has been making more and more use of graphic design features to more readily teach their readership about the scientific news and breakthroughs of the time. It is very common now to find full page diagrams and computer generated drawings of detailed processes accompanied by full paragraphs of text integrated into the images. This type of information design allows a much more clear and concise description of the issue at hand then pure text could ever hope to achieve. Students are now growing up with this type of information design and are exposed to it on a daily basis. As such, they are learning to process this style of information more readily.

Color television has also caused a change in communication. As in magazines and books, educational programs on television are now constantly full of computer generated animations and descriptions. Instead of merely reading about or hearing about the techniques used to build the Egyptian Pyramids, students can now sit and watch a special on the History Channel in which detailed animations actually show the techniques in practice. Students are growing up being exposed to this newer type of communication. Here again they are learning to more readily process and understand a certain type of information design and presentation.

The internet, arguably the most important development in recent history, also functions in the same manner. Websites today are filled with multimedia elements. Educational sites feature not only text descriptions of topics of interest, but can also include pictures, diagrams, sounds, videos, demonstrations, and complete online experiments. As an example, many physics education sites offer easy to use simulations of various physical effects. When students are learning about light they can use the online simulation to change various aspects of the experiment, such as the size of slits that the light is being shown through, and immediately see the results. This experimentation allows them to discover for themselves some of the properties of light.

Most teachers agree that this self discovery is one of the best ways to teach students new concepts (Interviews: Lowery, Hagerman). If there is not enough time or resources to complete the actual physical experiment, simulations such as these are the next best thing.

These changes in the presentation of knowledge in our everyday world, through color printing, television programs, and multimedia content on the internet, young students are learning to process and absorb much more visual and interactive information. By designing for a more visual approach to teaching, textbook designers are able to tap into this already developed visual literacy and put it to use in the school environment. Hopefully this alignment between skills learned in normal daily interaction and skills required to process information presented in school will allow the students to more easily learn and fully understand the concepts they are being taught.

The turn toward more graphic design styles has also been pushed forward by some of the widely supported concepts in teaching. While talking to teachers several key ideas came into light. One of these ideas is that students are better able to be successful in a subject if they are able to see the connection to their own lives. Students who are able to identify with a problem or concept, realizing that the topics being taught actually matter to them in one way or another, attach more importance to the topic. This boost in perceived importance then helps drive them to work hard to understand the subject. Many teachers believe that students are most readily able to see this connection if lessons are accompanied by or based on actual concrete examples. Abstract concepts are more difficult for the students to grasp and often make it more difficult to connect the idea to real life.

This focus on concrete examples has pushed textbooks to adopt a more visual approach to teaching. When students are able to see actual photographs or diagrams of the concepts being taught they are more able to see the connection that the subject under study has to the real world. For example, students in a biology class are asked to learn about many different animals and plants. While an extensive verbal or written account of the appearance of an animal almost always leaves some room for interpretation, a single photograph can often clear up any misconceptions the student had.

2.4 Student and Teacher Interest

It has been noted by educators that students take much more interest in learning a subject when they can become excited by the material. It is difficult for any student to focus on the task at hand when the material is found to be boring or unimportant. Because of this, teachers are constantly trying to find ways to make their material more exciting for students. The primary methods for creating excitement and interest among the students are creating projects or experiments that can be completed in class. Allowing a more hands on approach to learning allows the students to become more involved in the material, helping them to maintain focus on a subject which is no longer as tedious as it once was (Interviews: Hagerman, Lowery).

Group projects and experiments are viewed as the best way to teach a subject for multiple reasons. Not only does direct involvement allow the students to become excited about the material, but they are able to learn through their own experience rather than simply memorizing ideas that are taught by others. Learning material on their own allows the students to remember the concepts they've discovered more easily, and allows them to apply those concepts more readily to other situations in the future. It then would appear that students should be allowed to discover all of their material on their own. Teachers recognize that this would most likely be the best method, though experimentations take far more time in class than simple rote learning. For this reason, teachers must balance education through discovery with education through word of mouth. A textbook with good writing and strong visuals is a good middle ground (Interviews: Hagerman, Lowery).

It is also important to recognize that the excitement level of the student is tied closely to the excitement level of the teacher. It has been noted that students are much more perceptive than many would like to recognize, especially when it comes to the moods of their teachers. A teacher who is excited to be talking about his or her subject immediately rubs off his energy to the students. The students are able to see the topic under discussion as important and exciting because their superiors obviously believe it to be important and exciting. Similarly, students tend to show less interest in the subject when the teacher is teaching something that they obviously don't enjoy. Because of this connection, it is important for the teacher to be excited about and enjoy the subject they are teaching (Interviews: Hagerman, Lowery).

In order for a teacher to be excited about teaching their subject they must have a certain amount of expertise in the area. Teachers must feel that they have a significant amount knowledge above and beyond what their students already know. When teachers are confident that they have enough material to effectively teach, and in particular effectively answer questions posed by the students, they can be very comfortable with the material. Once comfortable with the material, a teacher can easily become excited in the subject if he has a personal interest in it (Interviews: Hagerman, Lowery).

Students are better able to learn when excited about the subject under discussion. Students can become excited when they see that their teachers are excited about passing on their knowledge in the area. Teachers are much better able to become excited when they have a strong grasp on the material being taught. When designing a teacher resource package for teaching a new subject it then becomes essential to include enough material for the teacher to feel confident in their knowledge level. Such a package must be able to teach the teacher first, and then provide materials to help the teacher to pass the knowledge on to their students.

2.5 Textbook Selection

When school systems decide that it is time for them to adopt a new book in a certain subject they have many choices available. The breadth of material that is covered in textbooks devoted to a particular subject at a particular level is fairly consistent between the various publishing companies. This is because the criteria that the companies use to determine what should be included are fairly standard in the industry. Schools must therefore make their decisions by taking into account many other features other than what concepts are included in the text.

One of the main elements that schools look for is how closely the textbook follows the order of their curriculum. Different teachers like to teach their subject in different orders depending on how they view the relationships between different ideas. Teachers like to find a book whose chapter arrangement coincides nicely with the order of material taught in the classroom. When the material in the book does not follow the classroom order of ideas then teachers must skip around between various chapters in the book as they progress rather than being able to continue smoothly from chapter to chapter in the book. Having a book which flows well with the preferred subject order helps instructors teach more effectively.

Another key element that teachers look for when selecting textbooks is the techniques that the book uses to teach the material. Some textbooks rely mostly on abstract concepts to teach their subject matter. In this kind of book, examples often use variables rather than solid numbers and rely heavily on material which was assumed to have been learned in previous courses. Other textbooks take an approach which can be tied more firmly to events in real life. These texts tend to have very detailed examples that use real numbers set in a realistic scenario. Concepts taught in these books are grounded in everyday life.

The teaching style of the books is important because teachers want to match the style of the book to their own style of teaching. In recent years teachers have been leaning more toward using detailed concrete examples in books. They believe that this helps the students to maintain a more firm grasp on the material being discussed. This is especially important for younger or less mature students, as many researchers believe that abstract thinking is not fully developed until the later stages of brain maturity. Teachers who agree with this new line of thinking would much prefer a book that takes a real world approach over a book which deals mostly in abstract concepts and ideas without binding those ideas tightly to reality.

Since teachers often look at many different books when trying to decide which would be the best to adopt next for their classroom, it is vitally important that a book also give a good first impression. Books which are able to garner positive reactions at the first stage of assessment can more easily maintain that positive attitude through the rest of the text selection process. The key to the first impression of a book is its visual design. Modern books that use a lot of color and graphic elements tend to be more appealing at first glance than books which have page after page of plain text. A teacher flipping quickly through a book is more likely to notice a creative diagram used to describe a scientific process than to notice a very eloquent passage of text amid a wall of additional text. For this reason teachers often lean, at least initially, toward more visually oriented textbooks.

Another important element in text selection is the ancillary package that is included with the text. This package of extra materials has grown more important in recent years as the internet has grown. Textbooks now are at a great advantage if they are able to incorporate a website which can offer additional. Textbook websites have several goals, including broadening the field that the book is able to cover and offering additional practice and assessment materials. The website can display simulations and additional stories to broaden the field. Additional links to outside sources can also be supplied for the same goal. Through use of these outside links the textbook and its additional materials are able to harness the vast amount of information that is available online.

Textbook websites also now often have additional problems that students can complete online. These problems are beneficial in several ways. The most drastic difference between problems completed online and problems submitted to the teacher is that the online problems can give immediate feedback to the students. The student can discover at once if he has completed the problem incorrectly and can then, while the material is still very fresh in his mind, go back and try again to find the correct solution. This is superior to the standard model of submitting solutions to professors as long as the student is able to help himself. However, if the student cannot find the correct answer on his own, then the teacher can determine the flaws in the student's logic much more easily if he is able to see the work turned in for grading. This additional material, both for extra information and for extra practice, plays a big role when teachers are deciding to adopt a particular book.

Also often included in the ancillary packages are exams for the teachers to use and ideas for projects and demonstrations that the teacher can do. While I have found that teachers often make their own exams so that the questions contained align more closely with what was actually discussed in class, the pre-written exams can help less experienced teachers to learn how difficult the included problems should be and the time frame that should be allowed for the exam. The teacher can use project and demonstration ideas to help maintain the students' interest in the subject. Safe and educationally valuable experiments and projects are often difficult to design, so having material that is ready for classroom use is a great boon for textbooks which are able to include such plans.

2.6 Content Inclusion

While the goal of successfully educating promising school children is valuable in itself, the textbook publishing industry is necessarily driven by profits. Publishing companies therefore include in their books that which will make their material the most enticing out of the field of book options available. The most immediate profits can be realized by tapping into the largest markets in the textbook world. These main markets are the California and Texas state school systems. These large states purchase textbooks for the entire school system at once, rather than leaving book selection up to the individual town school systems as in most states. Selling a book to California or Texas is therefore a very profitable situation (Laspina).

Since publishers concentrate on selling to these big buyers they tailor their books to the curriculums they use. California and Texas, because of the way they purchase their books, have a very large influence on the curriculum in the books that are used throughout the entire country. The California school system in particular has shown interest in books which are more visually appealing. The first book publishers who started taking this visual design philosophy to heart were rewarded with the approval of the state and helped to drive the shift toward more visual books throughout the entire industry (Laspina).

Because the basic principals of a subject, particularly in science, rarely change, book publishers do not have much of a need to change their content as new editions are released. Instead, publishers reshape the way that their material is taught, including more visual elements and improving on the examples that are used to help teach the concepts under discussion. While this information redesign can sometimes be fairly extensive, it is rare that a substantial amount of new material is added to the textbook. Because of this method of updating textbooks, the amount of cutting edge science that is included is not nearly proportional to its importance in current technology.

Additionally, there is a reasonable amount of lag time between the book being finalized and actually being printed and shipped. A chemistry teacher who recently went through the process of selecting a new textbook actually had a pre-print copy of a 2007 chemistry text for evaluation purposes. He opened the front cover, pointed to the periodic table of elements that was printed there, and noted that it was already out of date. Apparently scientists had just recently confirmed the detection of the most massive element to be observed, which would occupy the next space in the periodic table. He noted that textbooks often are a minimum of one year behind the most recent advances, and that new technology is often not included for much longer because of the necessity to create new content for the new material.

For all of these reasons, textbooks do not include a reasonable amount of coverage about cutting edge science and technology. The most that is usually seen in a book is a small note in the margin talking about the possible applications of some of the newest discoveries, which are usually already as many as five years out of date. Instead of putting a lot of effort into creating brand new content for the newest technologies, publishers tend to stick with the basics that must be covered according to their guiding curricula.

While the attitudes and practices of the textbook publishing field are a major reason for the gap between the material covered in the textbook and the real science of today, another factor is that schools do not replace their textbooks very often. The schools which have a significant advantage in funding can afford to replace their books every three or four years. While books which have just been purchased will be reasonably up to date, once the books begin to age the gap will become more and more pronounced. School systems which have even a moderate amount of funding can only afford to completely replace their books every eight to ten years. This is because the school must pay for the entire set of books, as high school students do not own their texts. Toward the end of the lifetime of a set of books it can then be seen that the gap between current technology and the material in the book can be as large as fifteen or more years. A gap this large is unacceptable when we are trying to give our nation's children the best possible science education. This gap can be filled by the supplemental teaching package that I am designing.

Despite the lack of materials currently available, teachers have expressed interest in being able to teach the most recent advances in science and technology. Teachers tend to be excited about the recent advancements in their fields of interest, and would like to pass that enthusiasm on to their students. If a teaching package were made available that would include enough materials to make the instructor feel confident enough to teach the subject then the majority of teachers would take some time out of their normal lessons to include the newest advances in science.

Teachers also believe that their students would be interested in learning about cutting edge science. As mentioned before, students are more able to become excited about a subject when they can see the connection that it has to their daily lives. Recent advances in science are often on the news, in magazines, and present in new electronics that are used everyday. Students would be excited to see the way that their new gadgets work, such as the technological advances that made the tiny high capacity drives in the Apple iPod possible.

The biggest concern that instructors had about teaching this new material is that time is already their most precious resource, and adding another chunk of material would only compound the problem. The reason that teachers don't include as many experiments and demonstrations as they want to is that they simply do not have time to cover the requirements for the year if they spend a lot of time doing these hands on activities. These requirements for the year are outlined in the state's frameworks.

The key to being able to teach cutting edge science then is to include it in the frameworks. The Massachusetts frameworks are decided upon by a panel of teachers and other education professionals who meet each year to make changes and updates. Mr. Lowery, the science department director at Shrewsbury High School, attends these meetings each year. He indicated that if a package were made available that would give teachers the required material that they would need to teach cutting edge science effectively then the panel of teachers would most likely approve a framework requirement for teaching children some of the newest advances in science and technology. While this process would likely take a long time to complete, the addition of the most recent science to the curriculum would be a positive move.

The other option for fitting in modern science is to find ways to include it in the current curriculum. The main way to do this would be to replace current examples used to explain various concepts and replace them with examples that integrate recent advances. As an example, the Massachusetts High School Science Standards include the following requirement in the Construction segment of the Technology/Engineering section: “2.1 Identify and explain the engineering properties of materials used in structures, such as, elasticity, plasticity, R value, density, and strength.” Each of these terms is equally applicable to the recent nano-construction material known as carbon nanotubes. If given the proper teaching materials, the instructor could integrate information about the very recent development of carbon nanotubes into his standard lesson about material properties. This would allow the cutting edge information to be classified as a contributor to one of the curriculum requirements for the state, and would therefore not be viewed as a waste of valuable classroom time by teachers or administrators.

3. Design and the Curriculum

There are many different ways to approach the integration of cutting edge material into high school curricula, though the most appropriate method to use in each case is dictated by both the purpose for including the material and the relationship of the new material to the old. If the new science is being used primarily as an exciting example of an idea which has already been presented, then the material can have a very strong tie to the textbook, and may even be included directly. If the purpose is to instead teach an entire concept using cutting edge science then the material can be separated from the main text and used as a supplementary lesson on its own. If the discipline which covers the new material is very closely related to the current material, such as the discussion of a new species in a biology class, then the cutting edge lesson can be more closely integrated with the primary text. If instead the new science is very multidisciplinary, as is often the case, then the cutting edge lesson cannot be as closely linked to the main textbook.

An example of new material which would be best used when closely integrated with the text is demonstrating conservation of energy with some elements of hybrid cars. Many hybrid cars are able to reclaim energy when they are breaking, charging the batteries for use later on. Through use of the laws of conservation of energy and by talking about the efficiency of the system the students will be able to determine the approximate value of gasoline that is saved by implementing this hybrid system. Students would be able to relate to this example in a real world way and would be excited to learn about a new technology which has been very prominent in the media and in society over the past few years.

There are several reasons why this example would best be used as an actual printed example in the primary textbook or as a supplementary example very closely related to the topic under discussion. The hybrid car idea is being used to exemplify a very specific effect in physics, namely conservation of energy. This concept is very important in physics and would be included in any standard high school curriculum guideline. Since the idea under discussion is already in the curriculum, the primary text will already cover the most important points for the topic. As such, it is not necessary to include a discussion of this conceptual material with the new cutting edge materials. Instead, new hybrid car science is used as a strong example to show the importance of the concepts which have already been discussed and to offer practice in applying those concepts.

An example of a cutting edge technology that would not be as closely tied to the current main text that the teacher is using would be a discussion of nanoscale machines. Technology has advanced to the point where engineers are capable of shaping individual molecules into prescribed shapes to be used in incredibly tiny machines. The main idea behind studying this new technology would be to try to garner an understanding of the huge range of scales in the universe. Students would be asked to find the number of these molecules that would be needed to fill up a shoebox, or perhaps a thimble. Once students begin to grasp the staggering difference in scale they will be excited to have discovered an entirely new world.

Included in this lesson could also be the newest advances in telescope technology, now allowing scientists to study objects further away than ever before. Students can be exposed to ideas like the size of a star, a galaxy, a supercluster, and the whole universe.

This will balance the analysis of scale by studying the other extreme. Discussion of this new technology will broaden their view of the world and allow them a glimpse into the study of the super small and super large.

This discussion of scale through cutting edge technology does not fit as neatly into current school curricula. The ideas presented are important in many different fields, including nano engineering, chemistry, physics, and astronomy. A discussion of the extremes of scale would be appropriate in any courses covering these topics. As such, there is less that can be assumed about the current understanding that the students have. This new material would therefore be required to teach actual conceptual material rather than simply be used to exemplify ideas which had already been discussed at some length.

3.1 Package Elements

When considering developing materials for a teacher to use for teaching cutting edge science it became clear that the teacher would likely have very little prior knowledge of the topic. Additionally, teachers will not feel comfortable teaching a new subject unless they are confident that they themselves understand the material and feel that they have enough information to teach their students. Teachers must also feel that they can fairly evaluate their students' progress in learning the subject. In order to fulfill the information requirements for a package designed to open up an entire new field for instruction many different information elements must be used.

The primary element in the teaching package is the information section of the student textbook. The information section consists of text and images used to describe and teach the actual concepts of the subject. Also included here are examples and scenarios where the presented knowledge would be useful in real life. The primary goal of the information section of the student textbook is to act as an aid and a resource for the students to supplement the classroom teaching by the instructor. Content in this section is designed for the appropriate age group, high school students in this particular case. The text itself should be of an appropriate reading level. Care must be taken not to assume an unreasonable level of previous experience in math or in other sciences.

The main student text is supplemented by additional text designed for the teacher. The teacher's book contains some information and concepts beyond those discussed in the student text. When the same information is contained, there is much more depth in the material in the teacher's edition. This additional material can be written at a professional reading level, and can be much more thorough and detailed about the subject under discussion. A much higher level of prior experience can be assumed in math and in other relevant sciences so that more advanced topics in the subject can be touched on.

The reason that more information is included in the teacher edition is because the teachers are able to handle the more advanced topics. This additional information should help them to more thoroughly understand the underlying concepts, allowing them to teach the material more effectively. Also, this additional knowledge gives an advantage to the teacher of knowing more about the subject at all times. This is helpful both in boosting the teacher's confidence in being able to teach the subject effectively, and in allowing the teacher to answer student questions which may not be answered in the student text because the information is somehow out of the scope of the student material.

A successful teaching package must not only include informative sections but must also include a way for the teacher to assess the progress of his or her students. The most common method for determining the knowledge that a student has gained is by giving problems to complete at home or in class. Effective problems cover all of the basic concepts discussed in the section and increase in difficulty to cover the more challenging ideas. A teacher can learn a lot from student problems, not simply whether they are able to get the questions right or wrong. The methods that students use to solve problems can demonstrate strengths and weaknesses in the student's knowledge. This feedback can be used to teach more effectively, by going back to cover some ideas again or by adjusting the teaching method for the next year.

Problems and exercises are also used to give the students practice in applying the concepts that they've learned. A concept is more readily reinforced when a student can see how the information they've learned can be used to solve a particular problem.

Consistent use of the concepts learned also helps them to remember the ideas for later applications. The primary uses of problems and exercises are to give the teacher feedback about the progress of his or her students and to give the students practice in applying the concepts under discussion. It is important to include practice problems in the teaching package because they can be time consuming for the teacher to create and as such personally created problems may not effectively cover all of the ideas in the section.

Another important part of student assessment is exams. The current style of teaching in the United States calls for an eventual exam to be given to see if the student has satisfactorily learned the material in the allotted time. Exams are used almost purely for assessment, as it is almost always too late to return to previous topics if an exam reveals that students do not have a good grasp on a particular topic. Teachers can, however, use this feedback to help plan their teaching in the future. It is important to provide exams in the teaching package because it is once again very time consuming to create fair problems for the students. Including prepared exams in the teaching package allows teachers to be more confident in the fairness and topic coverage of the exam.

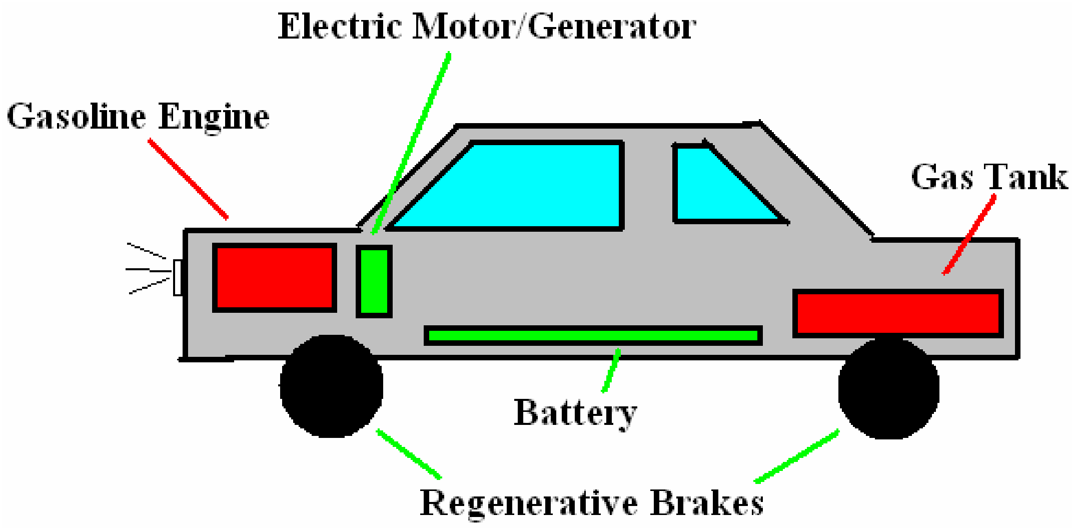
The teaching package should also include aids to help the instructor teach the material in class. In particular, ideas should be included for demonstrations that the teacher can perform. Since students learn more readily when they can see the actual effect that a concept has in the real world, teachers find it important to occasionally hold actual demonstrations to show the ideas being taught. As an example, if the effect combining two particular chemicals is a small explosion then a demonstration could be used to enhance the effect of the discussion. If the explosion was only mentioned to the students, then they may forget the idea being taught. If instead the chemistry teacher places a transparent blast shield around a beaker and then combines the chemicals to actually show the true explosion to the students, then they will remember the concept much more clearly. Ideas for demonstrations such as these should be given to the teachers so that they do not have to take the time to create such demonstrations on their own.

Not only do students learn more readily when they are able to witness the results of a concept in the real world, but they are even more able to absorb material when they can apply it in a hands on project or experiment. While experiments and projects take the most amount of classroom time, the act of self discovery helps the students to best learn the subject matter. The teaching package should include ideas for projects and hands on experiments that the students can perform so the teacher does not have to come up with these ideas on his or her own. Experiments should include detailed instructions and materials lists, along with any notes about how the teacher can help to enhance the experience. Experiments listed in the teacher package are also helpful because the teachers know that the experiments are safe and able to be completed in a certain amount of time. This saves the instructor the necessary steps of refining a laboratory experiment so that it meets reasonable safety and time requirements.

Finally, the teacher resource package should include a way to access additional information and material on the subject. Specifically, a website should be available which works in tandem with the book but which does not necessarily have to stay as closely tied to the curriculum of the book. This website should allow the students and the instructor to explore other interesting information related to the subject being taught. Simulations can easily be included for concepts both in the book and outside of its scope.

These simulations can emulate the self discovery teaching method to allow the students to conduct experiments in their own time. The website should also include a section of links to other internet sites which cover similar material and which may be of interest to those excited about the subject matter.

Hybrid Cars and Conservation of Energy

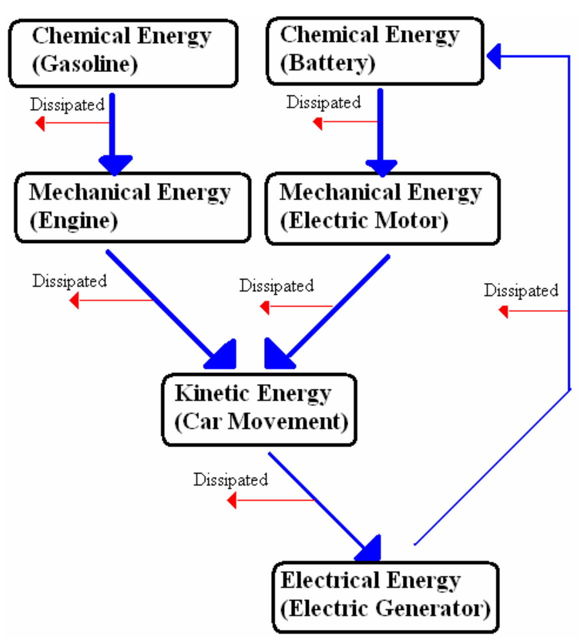


What makes a hybrid different?

While most regular cars use only gasoline to drive their wheels, hybrid cars also make use of electricity. Hybrid cars actually have two separate motors. One runs on regular gas, the other runs on electricity. The electric motor gets its power from a large battery in the car. Most hybrids do not actually plug into a wall in order to charge their batteries. So how do the batteries become charged? One of the main ways that the battery can regain some energy is through the use of regenerative braking.

When a car is in motion it has kinetic energy. The kinetic energy of the car is related to its mass and speed, and the mass of the car does not change. Therefore, to slow the car down, kinetic energy must be dissipated. This energy dissipation is the job of the brakes. The kinetic energy of the car is turned into heat, wear, and noise by the brakes.

In a normal car, this energy is lost to the environment. Many hybrid cars are instead able to reclaim some of this energy to store in the car's battery. This energy can later be used to help accelerate the car again, resulting in less use of gasoline.



The car does this by making use of 'regenerative braking.' Instead of only applying the regular brakes, the car also uses the wheels to spin the electric motor. An electric motor running backwards (the wheels spinning the motor, instead of the motor spinning the wheels) actually acts as a generator. The generator takes some energy from the wheels, slowing the car down, and moves that energy to the battery for later use.

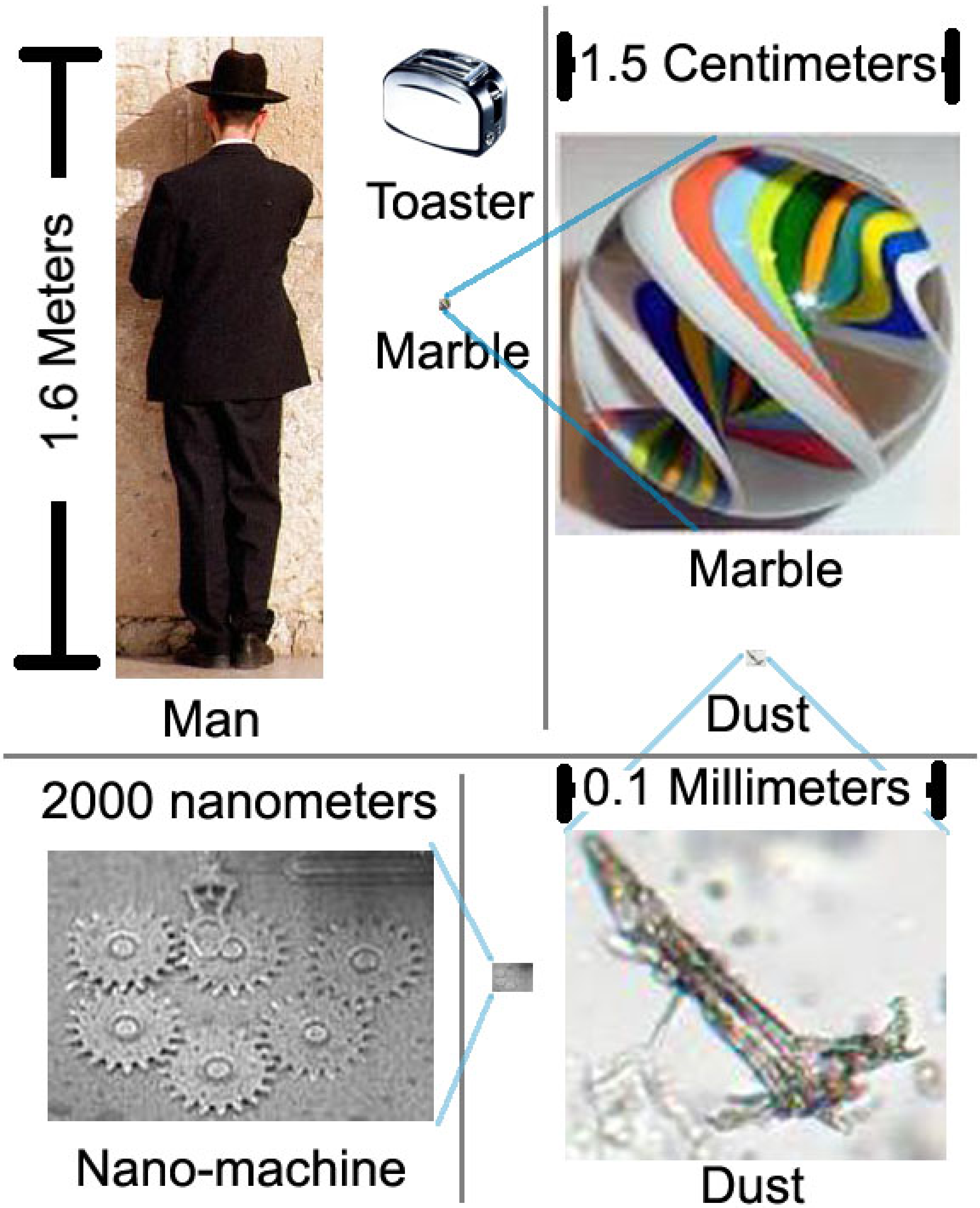
Conservation of Energy

In any real world system the total amount of energy involved always stays constant. Since this is the case, the main concern for engineers is to put as much of that available energy to good use as possible. When a car accelerates it is changing chemical energy stored in the gasoline into kinetic energy – the speed of the car. Much of the energy is actually lost during this transition, in heat, noise, and other ways, so that only a small percentage of the total energy in the gasoline actually makes the car go faster.

Engineers can use this same idea when the car is slowing down. The kinetic energy in the car can be converted back into chemical energy in the car's battery if you have the right device to facilitate this conversion. In this case, the electric motor in the hybrid can be used as an electric generator. This process is also fairly inefficient, but the energy regained can later be used to accelerate the car again, and the process is good enough to have an impact on the mileage that the car is able to achieve.

Exercise:
Using the principals of kinetic energy, find the energy returned to the car battery if a 3,000 lb car decelerates from 60 mph to a standstill. This particular electric generator is able to store 10% of the energy from braking in the car's battery.

Nanotechnology and Scale



Nanotechnology

Many technological advances in recent years have allowed a fantastic reduction in scale. Computers and other electronics have been getting smaller and smaller ever since their introduction, and many tiny mechanical devices have been following suit. Nanotechnology is the field concerned with designing and building these tiny machines. Many of the problems and opportunities uncovered by these tiny devices are new and unique, resulting in a field of study rich in new advances and ideas.

Scale

The nanomachine depicted in the graphic is actually one of the larger ones. At the very forefront of this field scientists have begun to work directly with individual molecules, though such designs tend to be very difficult to manufacture. Working with machines on the order of a thousand nanometers is becoming routine.

Due to their tiny size, components are often measured in nanometers, giving rise to the name of the field, nanotechnology. The prefix 'nano' means one billionth, so in this case engineers are working with constraints of only a few billionths of a meter. The most cutting edge work in the field actually involves designing molecules that form into incredibly tiny devices. To aid this process, some companies have begun compiling libraries of molecules which can be assembled like LEGO pieces to create many different possible devices. This approach helps the problem of manufacturing because one set of pieces can be created to actually build myriad different devices. These molecular building blocks tend to be only 200 to 300 picometers in size. There are 1000 picometers in one nanometer.

Difficulties with Nanotechnology

The continuing trend toward miniaturization in computers has led scientists to the point where conventional engineering techniques are no longer robust enough to address the problems. The minuscule forces of mechanical parts, the effects of electrical wiring spaced very closely together and fragility of tiny components are just some of the newer problems that engineers and scientists have had to face. On the scale of nanotechnology components can be bent or moved because of minute changes in magnetic force, electric currents can arc over the small gap between wires resulting in short outs, and very small particles can completely jam a nanotech machine. Engineers have been combating these problems by becoming ever more proficient at controlling these forces and environments.

There are also new health concerns associated with nanotechnology. Many of the newest machines are small enough that they could easily be lifted by a breath on a table and accidentally inhaled, all without the victim knowing it was happening. The effect of small machines roaming around in a person's body is almost completely unknown, and scientists and engineers have to be careful that they do not expose people to potentially dangerous situations. There are government regulations addressing most other dangerous materials, but they have been slow in adopting guidelines for the handling of nanotech devices. The risks involved must be carefully considered before such devices are used in commercial products used by the general public.

Implications of Nanotechnology

Nanotechnology is so new that the potential uses for the technology are growing daily. The idea of being able to design and build something so small is completely new to the scientific community, and as such the field is wide open to new creative applications.

Some of the more common ideas include further miniaturization of computer components, resulting in lighter, faster units that are able to cram more computing power and storage capability into a very small package. Many ideas are also emerging in the health industry, such as a small nanotech box which can hold a tiny dose of medicine inside. The boxes can be put into a liquid and injected like a regular shot, and the boxes can be instructed to open only when they have reached the right location in the body. This has the effect of delivering the medicine right where it is needed. Ideas like these are truly novel and would be impossible without the aid of nanotechnology.

Exercises:

A scientist creates a part for a nanomachine by combining 50 molecular building blocks in a straight line. Each of these building blocks is 250 picometers long. How many of these nanomachine parts would be needed to stretch from one side of a printed period to the other – a distance of half a millimeter?

In the novel Prey by Michael Crichton, a fictionalized scenario involves injecting tiny cameras into a patient. These cameras then orient themselves inside the patient's body with the aid of magnetic forces from a machine around the person, and the images are combined to form one large image of a damaged area inside the person's body. In a group, think carefully about the possible uses of nanotechnology and try to come up with a few possible applications which would not have been possible without the availability of such tiny devices.

Genetic Algorithms

What is Evolution?

Evolution is a widely accepted theory regarding the way that life has developed. Evolution is based on the idea of natural selection. Essential to evolution are the concepts of DNA, genes, reproduction, and mutation. Evolution is one explanation for why various animals and plants are shaped the way they are, work the way they do, and continue to thrive in drastically different environments.

How Evolution Works

Evolution works by causing changes in the DNA of plants and animals as each generation continues on. The main idea is that the individuals who are the best adapted to the environment will be able to survive more effectively and have more offspring. Since the parent passes on its traits to its children through DNA, this means that the new generation of creatures will be likely to have characteristics similar to the strongest of the old generation and dissimilar from the weakest of the old generation. In this way each generation of creature is better adapted to its current environment.

One of the greatest things about evolution is that the concept is applicable to almost any situation. As long as some of the creatures in a population are able to reproduce, evolution will help to pass on the strongest characteristics to the children of that population, no matter what the situation is. Because of this, evolution is able to change creatures as complex as plants living in very dry deserts or as simple as tiny bacteria living deep on the darkest ocean floor. The only requirements for evolution are a set of creatures to pass on their genes.

What Evolution Needs

Once scientists began to understand the theory of evolution, some noticed that evolution was really a problem solving technique for finding a way for creatures to survive in different conditions. Seeing this, the scientists recognized that the ideas behind evolution could be applied to other kinds of problems, not only designing living organisms. In order to apply these ideas to different problems, they had to find out what the requirements were for something similar to evolution to take place.

One of the main elements of an evolutionary system is the thing that is actually doing the evolving. In regular evolution, this is the set of creatures. In a scientific problem, it could be various solutions that are evolving to try to solve a problem. These creatures also need an environment in which to live. Normally, this is somewhere on Earth. In a scientific problem, this would be a set of rules governing what can and cannot be done. Evolution also requires that there be some measurable outcome which can determine how fit a certain individual is. On Earth, the ultimate measure of how well an individual fits an environment is its ability to reproduce. In a different kind of problem, the measure is how well a particular solution answers the question. Finally, evolution requires some way for parents to pass their genes on to another generation, creating alterations in the genetic code along the way. In plants and animals, this is accomplished by having offspring with multiple parents. In a different problem, this would be a means by which old solutions were combined and changed to create a new set of solutions.

Computers Can Handle It

Once scientists had established the requirements for an evolutionary system, they realized that fast computers would be able to set up just such a situation. As an example, scientists were able to use the ideas behind evolution and genetics to create a program which finds the fastest way to travel between two points.

The first requirement is to set up the environment, which in this case is a simulation on a computer. For this travel example, a map was divided into squares with 100 squares to each side. A start and end location were selected, and some of the squares in the map were filled in to mark them as impassable.

The creatures themselves then had to be created. In this case, the population consisted of programs that were trying to reach the end location from the start location. The engineers designed the programs so that they could hold four different commands, corresponding to the four possible directions that they could travel. The DNA of each creature was then a string of these movement commands.

Next, a way to measure the fitness of particular individuals had to be developed. The engineers had to find a way to rate each program based on how close it was to reaching the finishing point. To do this, they created a system which took into account how close the program was to the end when it finished, if it did in fact reach the finishing point, and how many commands it took for the program to reach the finishing point. The best scoring programs would reach the finish in the shortest amount of time.

Finally, the engineers required a way for the programs to pass on their genes. This part of the system is governed by the genetic algorithms in the simulation. This is the most difficult part of the simulation, requiring the most amount of tweaking to get right. The genetic algorithms look at the scores that each member of the population receive, and then decide which programs are able to pass on their genes and in what way.

Passing on Traits

There are many different ways that traits can be passed on and altered for each generation of programs. Adjusting the frequency of each of these methods is the art behind genetic algorithms. If the right set of conditions are set up then the population of programs will move more quickly toward a solution to the problem.

Pass Through

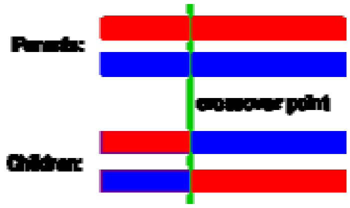
A copy of the program simply passes unchanged into the next generation. This can allow the strongest of the programs to continue on.

Crossover

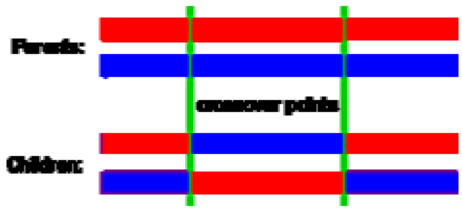
Two parent programs are chosen which are combined together in different ways to create new programs for the next generation. The idea is to hopefully create a child which has the strongest attributes of each parent, creating a better solution to the problem.

1. Single Point Crossover

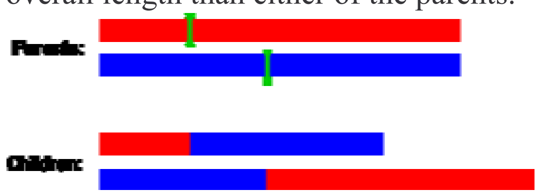
A single point is chosen in the programs and all of the information after that point is swapped between them.



2. Multi Point Crossover
Multiple points are chosen in the program, and some of the segments created are swapped between them. Below is a double crossover.



Splicing
Different points are chosen on each program and then swapped. Since the length before the break point on each program is different, the children will usually be a different overall length than either of the parents.



Mutation
Mutation is used because it is not necessarily true that the best solution is present in any of the parents of a particular generation. Random mutation allows new genetic information to enter the pool, creating more opportunities to reach the best solution. However, if too many mutations are used then the good parts of a program can easily be lost, making it very difficult to reach a good solution. The most common method for introducing mutation into a population is to change a small number of random instructions in the program to some other random instructions. In this case, one of the direction commands in a program would be replaced with a random direction.

Finding the Solution

Once the engineers created this problem and put the computer to work creating many generations of programs they found that the computer could almost always find the best possible solution for each given map. They also found, however, that the amount of time required to reach a good solution was not always well known. While the average time for evolving a program that reached the end point in the minimum number of moves was fairly consistent, there were several runs where it took a very long time to reach a good solution. Due to its reliance on some amount of luck, this tends to be a common problem with genetic algorithms.

Overall it has been shown that genetic algorithms and the ideas behind evolution can be used to solve all kinds of different problems, as long as the scientists understand the situation enough to be able to model the right environment in the virtual world of the program creatures.

3.5 Design Reasoning

In designing these prototype lessons, the primary goal was to expose the students to cutting edge technology while still teaching important concepts grounded in a solid science background which could fit into many existing curricula. Each of the designs was created with a different intended relationship to the other material that would be presented in the classroom. The designs are also meant to take advantage of the overall visual literacy of students of today.

The main idea behind the hybrid car prototype is the fundamental principal of conservation of energy. The total amount of energy in any given system must remain constant, and hybrid cars attempt to exploit this fact. This lesson is meant to be used in conjunction with other material that the teacher has for teaching the concept of conservation of energy. As such, the lesson does not attempt to actually teach the fundamental idea, but instead illustrates its principals through exposure to cutting edge science, namely the way that a hybrid car works.

The lesson begins with a diagram of the various components that are required for a hybrid car. It is important for the student to understand all of the different components that make regenerative braking work in a hybrid in order to understand the way that energy flows between each of these components. A text description of these different components helps the student to conceptualize the process. A flow chart illustrating the way that energy flows inside the car shows the student how regenerative breaking could help the hybrid to get better mileage with the same amount of gasoline energy.

The lesson about nanotechnology teaches students to consider the implications of designing machines on such a tiny scale. The goal of the lesson is to help the students to consider the applications and problems that could be associated with dealing with something that was so tiny. In order to help the students conceptualize something so tiny that regular microscopes are not generally able to see them in any kind of detail, a series of pictures was used. The series begins with something familiar and whose size is easily conceptualized, a man. Several images are then shown, decreasing in size. The next series begins with the smallest of the previous images, this time resized to be much larger. This is then compared to even smaller objects. The series eventually terminates on a nanomachine, with the students hopefully grasping a sense of how incredibly small they are.

This lesson is not tied closely to any particular class or related lesson. A good concept of tiny scales could be applied to such diverse scientific areas as biology, chemistry, engineering, and a host of other disciplines. The main drive behind the lesson is to get the students to begin to think outside the box in order to expand their problem solving abilities. The chance to discuss the implications of nanotechnology also allows the students to become excited about learning more about cutting edge technology.

The genetic algorithms lesson is designed primarily for a computer science course, though it could also be a very interesting addition to a biology or general engineering course. The lesson is not tied closely to any other particular lesson, though a solid grounding in the concepts of evolution would help, and an introduction to general programming would be required in order to implement an example of the genetic algorithms in action. The main idea behind the lesson is to introduce students to the idea that there are many different ways to solve problems and that the right problem solving tool can make a huge difference. Additionally, the lesson is meant to exemplify that many of the most recent advances in cutting edge science have been very multidisciplinary, requiring combined thinking from vastly different fields in order to make radically new technology.

The discussion of genetic algorithms requires a solid grounding in general evolution, so the lesson opens with an overview of the concepts involved. At first the students would likely not understand how evolution could be applied to problem solving, so evolution must be broken down into its constituents. It is then shown that each of these required pieces can be emulated on a computer, and that this emulation allows a program to harness the power of evolution to discover a solution to a difficult problem. The details of the computer process are described with the aid of visuals showing the emulated genetic coding that the computer recombines through its particular algorithms. The actual implementation of the emulator is not a difficult programming problem, and as such could be accomplished in a beginning or intermediate programming course.

4. Conclusions and Future Work

The design prototypes have demonstrated that it is possible to create a small supplement for teaching cutting edge science to high school students. These supplements are each applicable to several different fields, giving teachers and school systems a reasonable degree of flexibility when trying to fit the lessons into the curriculum. This flexibility also helps the publisher of the materials, since a broader range of applications makes any product more enticing. Based on the responses from teachers interviewed during the project, the interest in packages such as these should be high. This indicates a good deal of marketability for the materials. This demand should prompt publishers to begin designing and publishing this kind of material, both to help their profits and to help educate the children of America.

Future work for these materials would likely include responses from teachers and students about the effectiveness of the lessons, both in terms of educational quality and generating interest in the students for continued study of scientific disciplines. If students respond as anticipated and become more excited and interested in science and engineering careers once exposed to these modern materials, then we will have taken an important step toward renewing the scientific and technological leadership of the United States.

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