AN ANALYSIS OF GRAPHICAL REPRESENTATIONS IN ELECTRONIC

SCIENCE TEXTBOOKS

A Record of Study

by

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ABSTRACT

Advances in publishing and changes in the format of instructional materials have dramatically changed how we view the traditional textbook. This study investigates the nature of graphical elements used in newly adopted electronic instructional materials for teaching high school physics in Texas and also determines to what extent the graphical elements used abide by research-based tenets for effective multimedia learning. A previously developed survey instrument for traditional textbooks was modified to accommodate more interactive graphical elements (e.g., simulations, image maps, animations, videos, etc.). Four hundred and five graphics from six resources were reviewed by two independent coders for the study.

Analysis indicates that the digital materials reviewed range greatly in their use of graphical elements. Two of the resources contained few interactive elements, one of which was merely the publisher's traditional text in PDF form. At the other end of the spectrum were two resources that contained virtually nothing but multimedia elements, leaving behind the domain of static graphics and fully taking advantage of the twenty-first century's rich technological resources.

The resources fared well regarding their adherence to accepted tenets of effective multimedia instruction. There was virtually no extraneous material presented in the resources, a positive step towards eliminating the production of teaching materials that attempt to engage students by entertaining them with background music or superfluous video files. Of concern were the digital texts that incorporated multimedia elements in a

separate window or screen devoid of any text. Some of the resources contained print-based text materials that must be printed and referred to while interacting with the visual. This spatial disconnect between text and graphic raises serious concerns about educational/pedagogical value.

With an ever-expanding tablet PC market one can easily predict an exponential number of electronic texts flooding the market and demanding attention. The six resources reviewed in this study varied greatly in the content and quality of their graphical elements, and schools should carefully consider whether the new electronic resources deliver sound pedagogical content or are just providing digital "eye candy" for today's tech-savvy students.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Thumb through any science textbook and you will see that publishers have devoted a great deal of the available page space to illustrations - photographs, drawings, flow charts, tables, and graphs to name a few. Textbooks are becoming more visually appealing and include numerous illustrations on each page, many in color (Hubisz, 2001). The abundance of graphical elements makes today's textbooks look more like trade books (Walpole, 1998). State assessments are mirroring the trend. A recent analysis of standardized tests from fourteen states revealed that the majority of questions (52.7%) included a graphical element (Yeh & McTigue, 2009). Since textbooks are one of the primary means of communicating information in classrooms (Kesidou & Roseman, 2002; McFall, 2005) students are copious consumers of the multimedia message being delivered by today's textbook publishers.

But what is the future of the traditional textbook now that the digital revolution is in full swing? Will a stack of heavy textbooks be replaced by an e-reader in your child's backpack? The states of California and Texas have recently launched initiatives to implement digital textbooks and online resources as primary or supplemental source material for K-12 instruction, and other states are moving in the same direction (Hill, 2010). Apple has recently launched its own textbook initiative aimed at the K-12 market which includes partnerships with major textbook publishers to produce iBook versions of high school textbooks (Baig, 2012). Electronic versions of adopted textbooks have been available to teachers in recent years, but they have typically been merely a PDF

version of the textbook. Having the text available online provides some benefits, but does not take advantage of the rich multimedia capabilities of digital technology. Are the new digital textbook initiatives producing classroom resources rich with engaging graphical representations, or have publishers missed the mark and merely duplicated visuals in print-based media?

To help answer these questions a preliminary study was designed and conducted to characterize the nature of graphical representations and other multimedia elements in electronic science textbooks (Anderson & Slough, 2012). The analysis was based on the work by Slough, McTigue, Kim, and Jennings (2010) which analyzed the type and quality of graphics in four middle school science textbooks using a researcher-developed protocol. The researcher-developed instrument, Graphical Analysis Protocol (GAP), was modified to include the more interactive graphical elements into the e-GAP, which reflected the differing nature of electronic resources. In addition to focusing on the nature and number of individual graphical elements and how they relate to the electronic text, the study characterized additional multimedia elements (i.e., simulations, image maps, animations, videos, etc.) and analyzed whether these multimedia elements follow evidence-based instructional design principles espoused by Clark and Mayer (2011).

Graphics in online supplemental instructional materials for high school physics adopted in Texas were analyzed (Anderson & Slough, 2012). These materials were adopted in lieu of traditional textbooks for all science courses in grades five through eight and biology, chemistry, and physics at the high school level as a cost-saving

measure (Texas Education Agency, 2011). A total of 323 graphical elements from 169 pages of text were analyzed for the study.

Analysis of the data revealed that the electronic texts are similar to traditional texts analyzed using the GAP protocol (Slough, et al., 2010), in that they have large numbers of high-quality graphics and they do include some of more interactive graphical elements. Interactive graphics seem especially important for science classes where concepts can often be very abstract in nature and difficult to depict in a two-dimensional illustration in a traditional textbook. The integration of animations and simulations, especially those in which the user is able to manipulate variables, could greatly impact student learning in science. The multimedia appeal of online resources is without question, as students are increasingly immersed in a digital world full of animated graphics and video files that can teach them almost anything. Three of the resources (CompassLearning, Inc., 2011; ExploreLearning, 2011; Perfection Learning, 2010) analyzed in this study contained virtually nothing but this type of graphical element, completely leaving the domain of static graphics behind and fully taking advantage of the twenty-first century's rich technological resources.

Unfortunately some of the electronic texts did not take full advantage of the more interactive graphical elements, including one resource (Holt McDougal, n.d) that merely presents PDF files of the traditional text, or they were presented in such a way as to have questionable educational value. Of concern are the digital texts that incorporate multimedia elements in a separate window or screen devoid of any text. Some of the resources have print-based text materials (worksheets, simulation guides, informational

handouts, etc.) that must be printed and referred to while interacting with the visual. This spatial disconnect between text and graphic raises serious concerns about educational/pedagogical value. Will a student be focused enough to pay attention to information in a paper handout while interacting with the visual? What happens to the paper handouts after the lesson is over – will the students keep them in a notebook or discard them? And if paper handouts are necessary, would it not be a more efficient use of resources to have them in a printed and bound fashion (essentially a traditional textbook) that could be reused from year to year? One of the resources provided no text-based material to go with their multimedia elements at all, instead having a narrator describe what is happening on the screen and elaborating about the science content. This passive approach may appeal to today's students who live in a video-saturated world, but seems a potential mismatch for quality education.

The four resources reviewed in the study (Anderson & Slough, 2012) varied greatly in the content and quality of their graphical elements. Perhaps the ideal electronic textbook contains elements of all four – rich multimedia content that remains grounded with textual elements that actively involve the reader, helps build mental models and systems thinking, and adheres to cognitively-based principles of multimedia instruction. With the recent news that Apple is launching a new iPad textbook initiative one can easily predict an exponential number of electronic texts flooding the market and demanding attention. The implications of this for educators at all levels are staggering. Will traditional textbooks really be replaced by digital files on multi-touch tablets? Will the resources fully take advantage of the multimedia capabilities of today's devices and

include content that is both visually and contextually appealing to a new generation of learners? Will students get the educational message from electronic resources, or just expect to be entertained? These questions direct the focus of the proposed follow-up study.

Problem

The use of digital instructional resources (including application-based textbooks and stand-alone applications designed for e-readers, tablet computers or smart phones) in K-12 classrooms has increased significantly in the past few years. Today's students (often referred to as "digital-natives") have literally grown up with computers are typically more tech-savvy than their teachers. More and more students are coming to school with devices designed to use this content and increasing numbers of teachers are exploring how these resources can best be used in their classrooms. States are adopting digital resources in lieu of, or in addition to, traditional print-based materials.

Though a few years behind higher-ed, the K-12 market seems poised to fully embrace the digital delivery of content. But does the content deliver? The introductory study (Anderson & Slough, 2012) raised questions about publishers' utilization of multimedia capabilities of today's devices, the educational value of such content, and whether or not schools were ready to deliver this content.

Review of Related Literature

Benefits of Multimedia Learning

Students learn better when they learn with pictures and text than with text alone (Mayer 2009, Levie & Lentz in Butcher, 2006). Mayer refers to this as the multimedia principle, and he has conducted numerous studies characterizing the effectiveness of multimedia learning and instruction. Mayer's research is focused on the qualitative nature of learning (measured by improved understanding), versus the quantitative one (measured by volume of knowledge gained).

Mayer's multimedia principle is based on Paivio's (1991) dual-coding theory which proposes that information is processed by the brain in two different channels - verbal and nonverbal. The verbal channel processes words, sentences, conversations and stories while the nonverbal channel manages pictures, sounds, and sensations. Paivio found that although both channels function independently in neural processing they have additive effects when used simultaneously. By using both channels at one time the learner is able to keep more material in working memory at one time, thus allowing them to build mental connections between the two, resulting in greater in greater conceptual understanding (Mayer, 2009). Mayer's studies measure comprehension based on performance on recall and recognition questions and by transfer - the use of new knowledge to generate novel solutions to a problem or the ability to answer questions that are not explicitly covered in the lesson (Butcher, 2006).

In a study completed in 2003, Kristen Butcher compared learning outcomes when students were presented a lesson using text only, text and simplified diagrams, or

text with detailed diagrams. The lesson focused on the flow of blood through the heart and the researcher analyzed mental models represented by drawings of blood flow through the heart drawn by the students before and after they interacted with the instructional material. A mental model is a representation of key parts of new knowledge gained in a lesson and how the parts fit together. The construction of a coherent mental model is the desired outcome of active learning (Mayer, 2009). If a learner is presented with isolated facts that cannot be linked together or is given no guidance in how to construct a structure to hold the knowledge a coherent model may not be developed, and the desired outcomes may not be reached (Mayer).

Butcher's study of comprehension with different graphical presentations concluded that diagrams help students build mental models, but that simplified diagrams help the most. This confirmed her hypothesis, which was based on earlier research indicating the use of complex diagrams likely taxes working memory and interferes with processing. Simplifying diagrams reduces the visual search difficulty and draws attention to important details helping to link the verbal and visual processing channels and allowing the information to be processed simultaneously instead of sequentially (Koedinger & Anderson, 1990; Larkin & Simon, 1987 in Butcher, 2006).

But, as learners develop increased comprehension of material, simplified graphics may not provide enough challenge to fully engage in the learning task (Kalyuga, Chandler, & Sweller, 2000). It has been shown that there is a "reversal effect" as learners gain more background knowledge. Presentation formats that benefit novice learners (simple graphics and ample text) do not seem to benefit experts where a visual-

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only presentation was optimal (Kalyuga, 2006). These findings indicate that instructional designers should consider the level of background knowledge and the complexity of material presented when designing multimedia instructional materials.

Is dual-coding theory the only explanation for Mayer's proposition that students learn better with pictures and text than text alone? Larkin and Simon (1987) found that diagrams can be better than text alone for problem solving. Diagrams group salient information together in one place reducing the need for the learner to search multiple locations for important information. The information is then processed as a "chunk" reducing cognitive load and freeing working memory for retrieval of prior knowledge and/or association of knew knowledge to the problem solving situation. Conjoint retention theory (Robinson, Katayama, & Fan, 1996) suggests that processing verbal stimuli demands greater resources than visual stimuli. Presenting visual before verbal content allows the learner to process and place the content of the image in working memory then use it to help decode verbal information that follows. Presenting the verbal information first does not seem to enable the learner to as effectively construct a framework for interpreting new information presented in the graphic.

Graphics in Science Textbooks

Although one third to one half of the space in science textbooks is devoted to graphics, many of the graphical elements do not serve a clear instructional purpose (Levin & Mayer, 1993; Mayer, 1993; Woodward, 1993, in Mayer, Steinhoff, Bower, & Mars, 1995). Slough, et al. (2010), analyzed the type and quality of graphical elements in four sixth-grade science texts. The study found that a third of the elements analyzed

served no cognitive function and merely provided a decorative element to the text. In addition, most graphics and their associated captions (87.7%) showed an isolated unit with no connection to a larger system. A major theme in science curricula is the idea of systems. Systems have interacting parts, cycles or processes and are studied in terms of how the parts relate to each other and the larger environment (Texas Administrative Code, 2009).

Can graphics in science textbooks help students understand systems? Mayer and Gallini (1990) studied which types of text and graphical representations helped college students most effectively learn a systems-based concept - how the braking system of a car worked. Learners in the study were given either a purely text-based booklet to study, text with the parts of the system illustrated, text with the steps (processes) of the system included, or text with both parts and steps illustrated. Participants receiving the parts and steps presentation outperformed the control group in recall and problem solving. A similar study (McTigue, 2009) with sixth-grade students did not show the same results. The author notes that the ability to glean important content from graphics and texts is a higher-order skill more likely held by adults than middle school students. It is suggested that skills for decoding complicated graphics could be explicitly taught to younger students to improve cognition.

How should verbal and visual information be linked in a textbook? Mayer and his colleagues (1995) propose that explicit connections should be made between graphics and accompanying text. Direct connections between text and graphics (e.g. in text references to graphical elements such as "see the picture below" or including an

annotation with a graphic) help students successfully build mental models of scientific systems by integrating the verbal and visual channels. Teachers most often do not overtly instruct students on how to interpret graphics in the text, so providing signaling clues in the text will assist readers in integrating the text and graphic (Coleman, McTigue, & Smolkin, 2011). Annotating illustrations signals important words and images to readers, helps them organize information into cause and effect systems (especially by using a sequence of illustrations describing change over time or picturing a series of steps), and allows for elaboration and reinforcement of important content (Mayer, et al., 1995).

Are publishers following these recommendations? Data from the review of 6th grade science texts conducted by Slough, et al. (2010) shows that most of the graphics analyzed in the study were referenced in the text (61.9%). On the surface this seems like a large number, but if readers are not directed to look at a graphic, will they? Research (Levie & Lentz, 1982; Peeck, 1993; Pena & Quilez, 2001 in Slough et al.) shows that they might not. The study also showed that most graphics included a caption (81.5%), and that most of the captions were used to identify or describe textual elements, with only a few (9.3%) engaging the reader at a higher level, for instance asking the reader a question or posing a task.

A review of middle school physical science texts (Hubisz, 2001) cited some concerns about the quality of illustrations contained in those texts. The reviewers noted that a large number of photographs were irrelevant, that some illustrations were too complicated for students to understand, and that many of the diagrams and drawings

represented physically impossible situations. It was also noted that the addition of so many graphical elements made the texts "busy" and potentially confusing to the reader. Choosing a graphic type that successfully organizes information presented in the text (rather than presenting an attractive photo or illustration of the subject matter) supports the reader and helps build mental models (McTigue & Slough, 2010).

Do students value graphics in textbooks and actively integrate them with the textual material? Eye-movement data suggests that they do not spend much time (less than six percent of total reading time) looking at graphics (Hannus & Hyona, 1999 in McTigue & Slough, 2010). Also notable is that students feel that the role of graphics is to merely represent what is in the text and that they usually read the text before looking at the illustrations, suggesting a secondary role for the graphics (McTigue & Flowers, 2011).

Transition to Digital Resources

Are traditional textbooks on the way out? Will e-books become the instructional tool of choice? Teachers are using more technology resources in their classrooms than ever. A 2009 national survey concluded that 76 percent of K-12 teachers use digital media in their classrooms (reflecting an increase of eight percent in just one year), and that 78 percent of those teachers feel that that using technology in the classroom enhances student motivation (Public Broadcasting System, 2009). Recent adoptions of digital textbooks are pushing teachers in many states to transform traditional print-based lessons into more media-driven ones. Textbook publishers are increasing their digital offerings. McGraw-Hill (a major textbook publisher) offers 95% of its books for

education in digital format, but finds that printed books are still the focus of their business (Baumann, 2010). Although becoming common place in higher-ed, e-books make up only ten percent of the K-12 market (Baig, 2012).

When costs are considered, it is hard to ignore the benefits of e-books. The College Board estimates that the average university student spends $1,122 per year on textbooks (Baumann, 2010). States bear the cost of textbooks for K-12 students, but are increasingly seeing funding cuts making less money available for adopting and purchasing textbooks and are beginning to adopt e-books and other digital resources as a way to reduce costs (TEA, 2011). And what about carrying around those heavy books? A textbook in the hard sciences can weigh in at seven pounds - even carrying around a couple of these can be problematic. So problematic, in fact, that the California Department of Education capped the weight of textbooks for high school students at five pounds to reduce back strain (Baumann). E-readers can hold thousands of titles reducing weight and increasing portability and convenience.

The ability to access virtually limitless content almost instantly, almost anywhere, is a clear benefit to using e-readers instead of print-based resources. No longer do students need to "ask a librarian" that nagging question – a quick Google search on their smart phone or iPad has replaced that old-fashioned human-to-human interaction. Visual and auditory learners could especially benefit from using digital resources when media-rich content including video files, simulations, animations are added to the digital resources (Grensing-Pophal, 2010). In addition to the opportunity to add interactive and visually stimulating content to the instructional materials, e-books

offer several value-added features when compared to traditional textbooks including updatability, easy accessibility, and quick publication time (Landoni, Wilson, & Gibb, 2001). But in what format should publishers produce their materials? The popular e-readers (Kindle, Nook, and iPad) all use different formats and modes of distribution and publishers are refocusing their business model to adapt to the new technologies (Grensing-Pophal).

Studies conducted on the use of e-readers and electronic texts yields mixed reviews. One study (McFall, 2005) found that specially designed tools in the proprietary e-reader application designed to provide more active reading (highlighting and note-taking) were rarely used by students. The author notes that many students tend to be passive readers and that including tools in the e-reader to enhance engagement should result in increased cognition. It was speculated that textbook reading strategies are habits ingrained in students over many years, and that they can be difficult to change, even with the use of technology. A study comparing student attitude and performance when using either a print-based or electronic text (Shepperd, L., & J., 2008) found that performance (as measured by course grades) did not vary between the two groups and that students had a generally neutral attitude toward using the electronic version of the text. Notable about this study and another similar one (Woody, Daniel, & Baker, 2010) is that the electronic versions of the texts used included no interactive or multimedia elements and had to be used with a desktop or laptop computer.

When interactive features such as hyperlinks, interactive questioning, note-taking and highlighting were incorporated into an XML-based digital textbook designed for a

sixth-grade math class the authors found student performance was comparable with the control group, which used a traditional print-based book (Kim et al., 2010). They do note, however, that as students become more proficient in the use of the resource greater achievement could result. In addition, the program designed for the study allowed the teacher to customize lessons and assessments for students, facilitating differentiated and self-paced instruction.

The state of Texas is currently in an adoption cycle for science textbooks for all grade levels. Districts are currently reviewing materials submitted for adoption by publishers and will begin purchasing materials in the spring of 2014 for use beginning in the 2014-15 school year (TEA, 2013). A scan of the materials available for adoption reveals that virtually all of the resources available for middle and high school grades contain digital resources ranging from a stand-alone software curriculum package to PDF versions of traditional textbooks.

Research Questions

It is clear that the trend in education is toward using digital instructional resources in lieu of, or in addition to, print-based media. The proliferation of tablet-based computers is causing a shift in the tools used to access the newly-emerging digital resources. Thousands of instructional applications are available for these devices and publishers are increasingly making textbooks available for them. Digital resources will no doubt continue the trend established in print-based materials of including large numbers of high quality graphical elements, and hopefully the publishers/developers will full take advantage of the ability to include interactive elements such as animations,

audio and video files, simulations and the like. The goals of the study were to explore the following questions:

(1) What is the nature of the graphical elements used in the newly developed digital physics textbooks and instructional applications in Texas?

(2) To what extent do the graphical elements included in these resources abide by the research-based tenets for effective multimedia learning?

CHAPTER II

METHODS

Drawing on the work of Slough, McTigue, Kim and Jennings (2010) and

Anderson and Slough (2012), the goal of this study was to characterize the nature of

graphical representations and other multimedia elements in electronic science textbooks.

The 2010 study analyzed the type and quality of graphics in four middle school science

textbooks using a researcher-developed protocol. The Graphical Analysis Protocol

(GAP) developed by the researchers for the study focused on four principles (a) form

and function of graphics should be considered; (b) graphics should help learners develop

coherent mental models; (c) text and graphics should be spatially integrated, and (d)

graphics and text should be semantically integrated (Slough et al., 2010).

The GAP instrument was modified to include the more interactive graphical elements

into the E-GAP, reflecting the differing nature of electronic resources. In addition to

focusing on the nature and number of individual graphical elements and how they relate

to the electronic text, the study characterized additional multimedia elements (e.g.,

simulations, image maps, animations, videos, etc.) and analyzed whether these

multimedia elements follow evidence-based instructional design principles espoused by

Clark and Mayer (2011).

The following design principles were considered for the additional multimedia

elements:

Coherence - was extraneous material (e.g. background music or sound effects)

included that might distract the learner.

Redundancy - was textual information presented in both written and auditory format? Mayer and Clark (2011) have found that presenting textual information associated with a graphic in both textual and auditory format reduces the learners' ability to glean important information from the graphic.

Temporal contiguity - were corresponding words and graphics presented simultaneously rather than successively (Clark & Mayer, 2011; Mayer, 2009)?

Instructional materials designed for electronic delivery for high school physics were selected for analysis. Materials from six publishers whose materials were approved for adoption in Texas under Proclamation 2014 were analyzed. To define the sample, one topic was chosen from each of the five major physics content areas as defined by the state curriculum standards (Texas Essential Knowledge and Skills or TEKS): motion, forces, energy and momentum, waves, and modern physics (atomic, nuclear, and quantum phenomena). The state standards divide content into knowledge and skill statements for both scientific processes and scientific concepts. Each knowledge and skill statement is followed by a list of student expectations. Since electronic content may or may not be divided as a traditional textbook is into chapters, the content (wherever it appears in the online materials) from one TEKS student expectation from each of the major physics content areas was analyzed.

Two teachers currently teaching high school science in Texas were selected to collect the data for the study. Both teachers have extensive classroom experience – one has been teaching high school science in the same school district for fifteen years and the other has twenty years of experience teaching science at two different Texas high

schools. They have used a variety of instructional materials in their classrooms including traditional textbooks and publisher-provided ancillaries, teacher and district developed curriculum materials and online resources. The same coders were used for the preliminary study and so had familiarity with the E-GAP instrument and the data collection protocol. A training session was held with the coders to review the instrument and establish guidelines for the new project. During the training session a representative chapter from a traditional print-based physics textbook and a non-sample section of one of the electronic textbooks was coded collaboratively by the two raters with assistance from the researcher. Following the training session the coders independently coded another non-sample section of one of the resources. The data from the independent analysis of the non-sample section was reviewed and seven data elements (out of 312) were found to have been coded differently by the two coders. The researcher conferred with the coders to discuss differences in coding and to crystallize understanding of key definitions within the instruments. Over a period of three weeks in the spring 2014 all graphics in the selected content were then analyzed independently by the coders with the modified electronic Graphical Analysis Protocol (E-GAP) and coding key.

Following the coding of graphics, data for each resource recorded on the paper coding sheets was tabulated and entered into an SPSS file. Four hundred and five graphics were coded, each with seven to ten data categories, resulting in the collection of 3215 discrete data elements. Coding differences were found in a very small percentage (less than one percent) of these elements. The researcher reviewed the data and the graphic with which it was associated and made the final coding decision on those few

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data elements in which there were discrepancies. Descriptive statistics were run and examined for outliers and to check for data entry errors as well. Summary statistics for number of pages and graphics analyzed, multimedia proportion of the texts and overall values of the formatting, color choice, etc., were run.

CHAPTER III

RESULTS

Analysis of the results indicates that the digital materials reviewed range greatly in their use of graphical elements. At one extreme is the electronic text that contains little more than PDF files of the publisher's traditional text, including pages from their ancillary materials (e.g., a lab book) (McGraw-Hill, 2015). At the other extreme is a unique product that is part text and part software (Perfection Learning, 2010). This product is installed on the user's computer and features traditional text embedded with many illustrations, animations, and user-controlled simulations. In between these two extremes are online products that blend traditional text with multimedia elements such as animations, simulations, and video files (Ergopedia, 2014; ExploreLearning, 2014; Houghton Mifflin Harcourt, 2015; Sapling Learning, 2014).

A total of 405 graphical elements from 245 pages of text from six publishers were analyzed for the study (see Tables 1 and 2). Each page was analyzed for text structure, text/reader interaction, and multimedia proportion. Since online materials may not be traditionally numbered an alternate definition of *page* was developed for two of the six resources reviewed. When page numbers were not present a set of screens that composed a cohesive scene was considered to be a page. When the scene changed, the page changed. In all pages that contained text (75.1%), the text was presented in a traditional linear fashion where text is read from left to right and top to bottom. The remaining pages (24.9%) contained no text or text that was limited to labels in the

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graphics. Textual information for these pages was presented in audio format via a

narration.

Table 1
Graphical Element Count by Publisher

Publisher	Frequency
Ergopedia	97
ExploreLearning	17
Houghton Mifflin Harcourt	109
McGraw-Hill	50
Perfection Learning	94
Sapling Learning	38
Total	405

Table 2
Pages by Publisher

Publisher	Frequency	Percentage
Ergopedia	41	16.7
ExploreLearning	17	6.9
Houghton Mifflin Harcourt	82	33.5
McGraw-Hill	34	13.9
Perfection Learning	43	17.6
Sapling Learning	28	11.4
Total	245	100.0

The majority (85.9%) of text was presented in an informational/passive voice.

The following passage illustrates the passive voice in a section on projectile motion:

When a projectile is launched at an angle, the initial velocity has a vertical component as well as a horizontal component. If the object is launched upward, like a ball tossed straight up in the air, it rises with slowing speed, reaches the top of its path where its speed is instantaneously zero, and descends with increasing speed. (McGraw-Hill, 2015, p. 156).

A small number of pages (9.2%) had a more informal tone in which second person was utilized occasionally to sound as if speaking to the reader. For example, a passage in one of the texts used second person to help engage the reader and provide motivation for learning the material to follow with this passage introducing a section on universal gravitation:

You learned in elementary school that the Moon orbits the Earth and the planets orbit the Sun because of *gravity*. This section explains *why* by showing you how the law of universal gravitation bends the motion of the planets and the Moon into circular, or nearly circular orbits. (Ergopedia, 2014, p. 215).

The text on only a few pages (4.9%) encouraged active participation by asking the reader to make predictions, answer questions, etc. An interesting finding was that all examples of text using an active voice came from one publisher (Perfection Learning). This publisher regularly intersperses questions throughout the text and has numerous simulations annotated by text passages asking the reader to make predictions and develop hypotheses about the topic under study, including this passage accompanying a simulation illustrating gravitational forces between two objects:

You can move a mass around the screen and see how the gravitational forces

change. What is the relationship between the amount of the forces and the

distance between the masses? Do the masses exert the same amount of force on

each other? (Perfection Learning, 2010, p. 8.8)

Note that this variable measured the tone only of the textual elements and

whether they elicited active participation or not. Active participation often became part

of the learning process when the learner utilized some of the multimedia features on the

pages (simulations especially) discussed later. Notable was that the one publisher who

included textual passages written in an active voice (Perfection Learning) seamlessly

blended the active text with interactive multimedia elements. The other publishers

presented the multimedia elements as more of a stand-alone part of their package and did

not integrate the text in such an effective manner.

At the page level the coders determined the multimedia proportion - the balance

of text and graphics on the page. It was found that 52.2% of the pages contained more

text than graphics, 33.5% contained more graphics than text, and the remaining 14.3%

had equal proportions of text and graphics.

For the purpose of this study graphical elements were divided into two categories

– static graphics and multimedia elements. Static graphics were considered those that

were not animated or did not contain an audio narration providing the textual

information. These are the types of illustrations found in traditional textbooks –

photographs, color or line drawings, flow charts, graphs, etc. (see Figure 1 for an

example). One of the resources analyzed contained only static graphics since it was

merely a PDF copy of the publisher's traditionally printed textbook (McGraw-Hill, 2015).
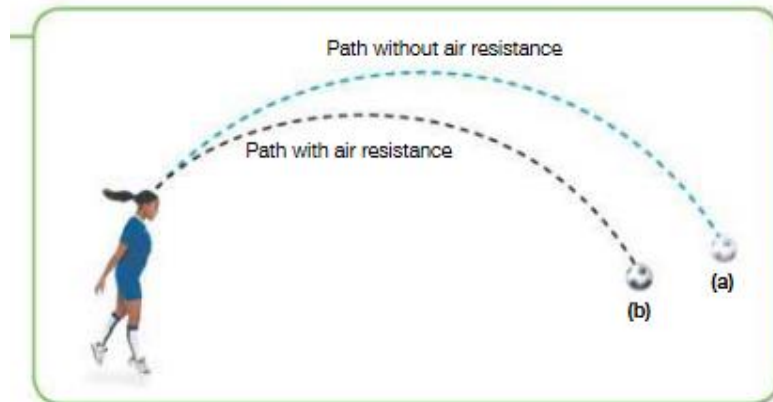
Houghton Mifflin Harcourt, 2015

Figure 1. Example of a static graphic.

On the other end of the spectrum were two other resources that contained virtually no static graphics, only multimedia elements (ExploreLearning, 2014; Perfection Learning, 2010). Multimedia elements included animations, simulations, audio and video files, and image maps (see Figure 2 for an example). Static graphics and multimedia elements were further categorized and then coded by type (see Tables 3, 4, and 5 and Figures 3, 4, 5, 6, and 7). An interesting finding was the predominance of drawings and flow charts (67.5% of the total) in the materials and the lack of tables and graphs (5.2% of the total). This seems unusual given that these are materials for a high school physics course, but does seem to follow the trend of making textbooks look more like tradebooks.
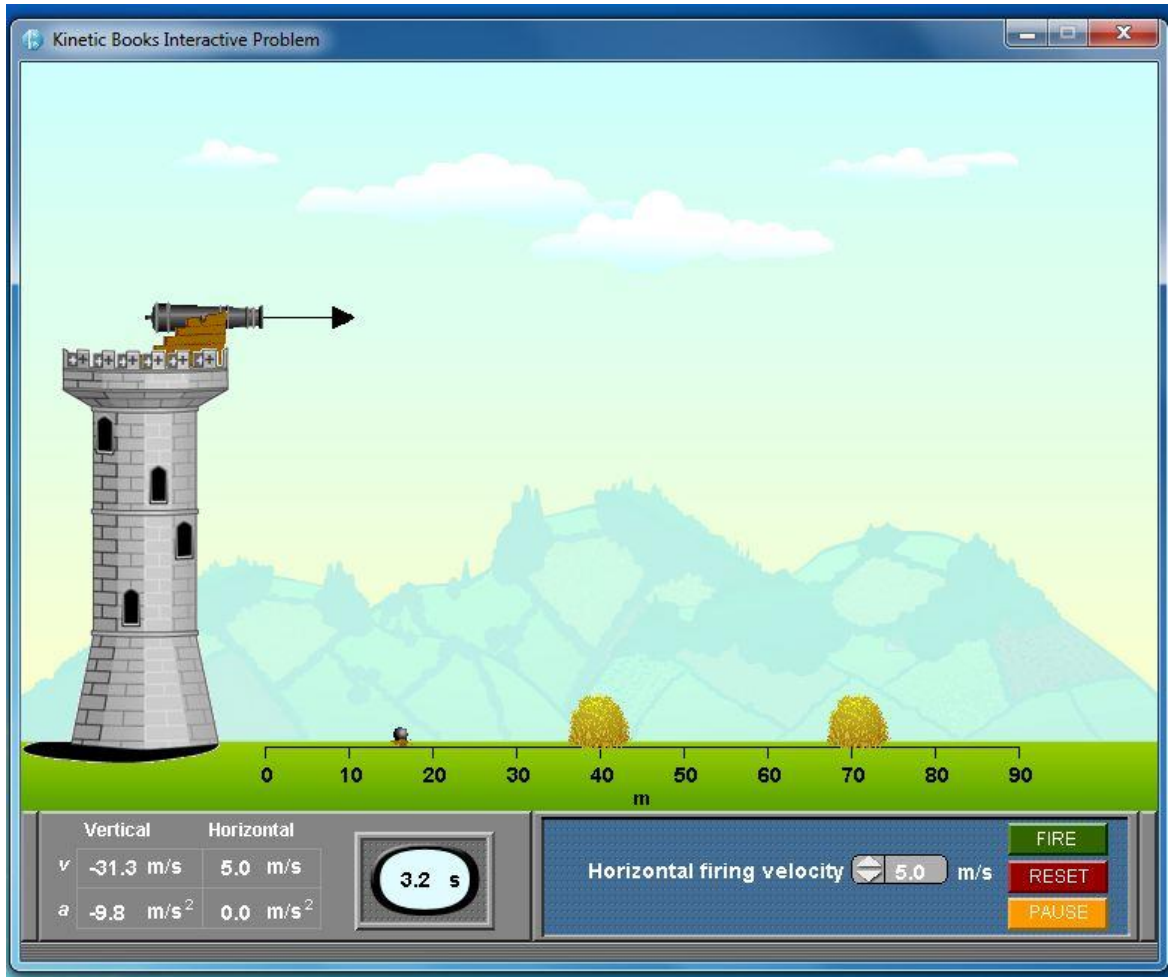
*Figure 2.* Example of a multimedia element.

Table 3
Distribution of Graphical Element Types by Publisher

Publisher	Number of Static Graphics	Number of Multimedia Elements	Percentage of Static Graphics	Percentage of Multimedia Elements
Ergopedia	78	19	80.4	19.6
ExploreLearning	0	17	0	100
Houghton Mifflin Harcourt	50	59	45.9	54.1
McGraw-Hill	50	0	100	0
Perfection Learning	1	93	1.1	98.9
Sapling Learning	36	2	94.7	5.3

Table 4
Distribution of Static Graphic Types

Type of Static Graphic	Frequency	Percentage
Photograph	32	14.9
Naturalistic drawing	19	8.8
Stylized drawing	21	9.8
Picture glossary	46	21.4
Scale diagram	17	7.9
Flow chart - circular	4	1.9
Flow chart - linear	37	17.2
Cut-away/cross section	1	.5
Table	4	1.9
Graph	7	3.3
Hybrid	27	12.6
Total	215	100.0
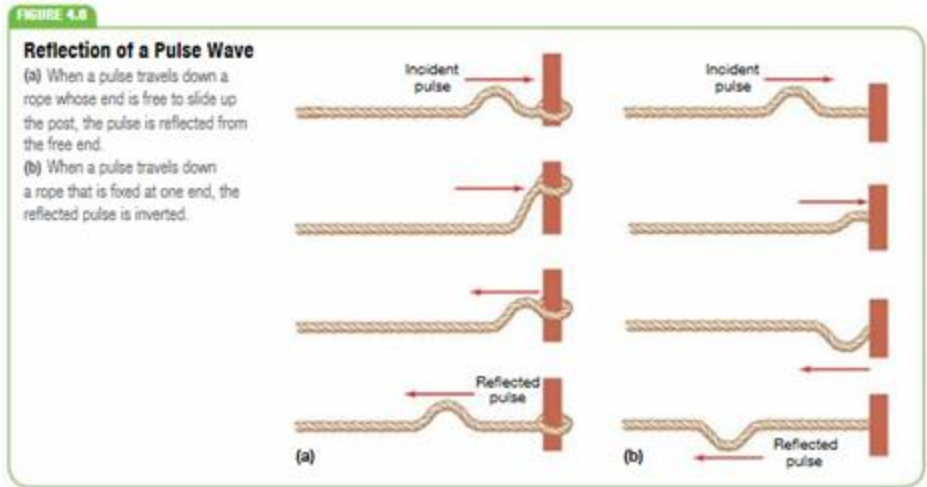
Houghton Mifflin Harcourt, 2015

Figure 3. Example of a linear flow chart.
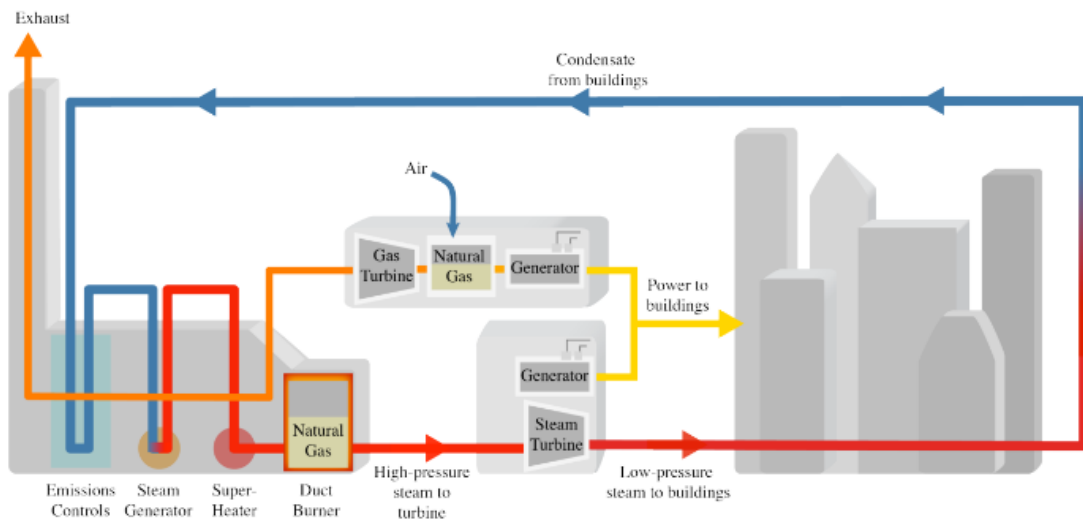
Sapling Learning, 2014

Figure 4. Example of a cut-away/cross section.

FIGURE 4.7

Standing Waves (a) This photograph shows four possible standing waves that can exist on a given string.
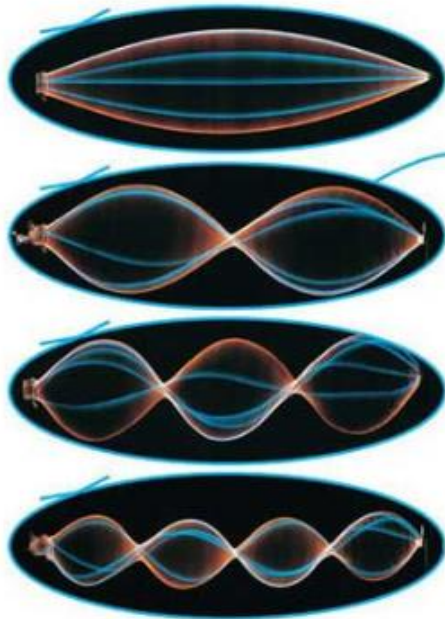
(b) The diagram shows the progression of the second standing wave for one-half of a cycle.
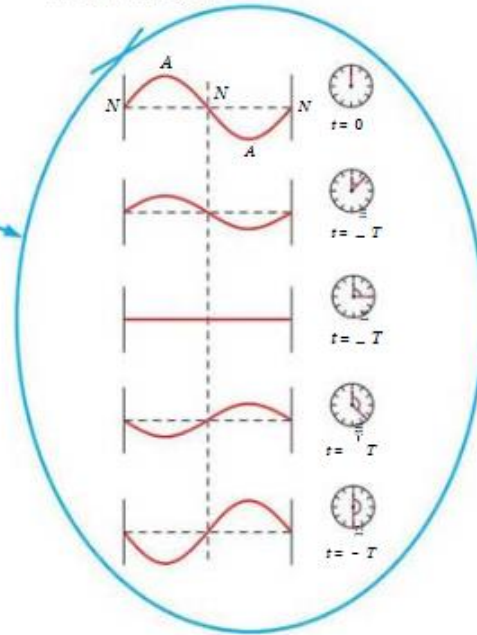
Houghton Mifflin Harcourt, 2015

Figure 5. Example of a hybrid graphic.
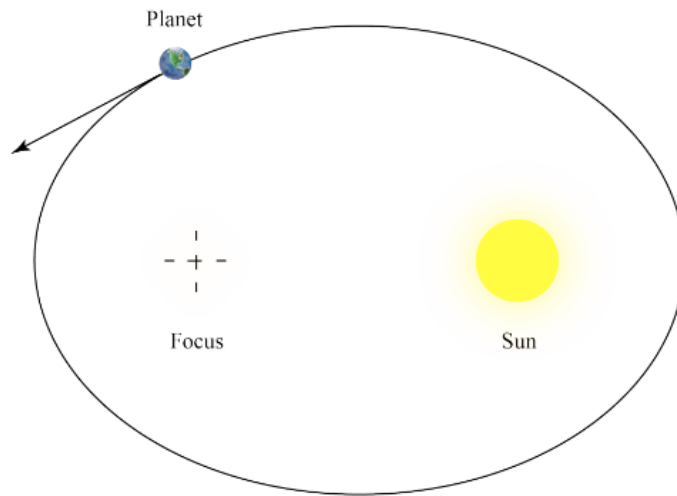
Sapling Learning, 2014

Figure 6. Example of a stylized drawing.
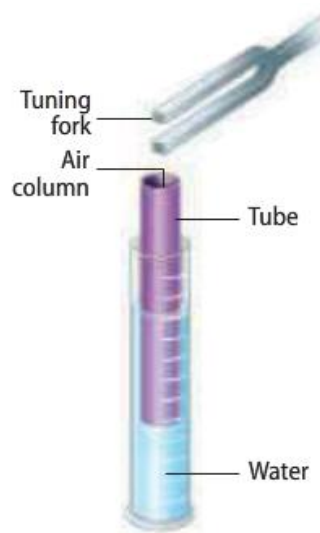
McGraw-Hill, 2015

Figure 7. Example of a naturalistic drawing.

Table 5
Distribution of Multimedia Element Types

Type of Multimedia Element	Frequency	Percentage
Narration describing a graphical element	64	33.7
Image map	6	3.2
Animation	62	32.6
Video	5	2.6
Simulation	53	27.9
Total	190	100.0

One of the concerning notes concerning the static graphics was the outcome of the systematicity variable which measured how well the graphic and associated text in captions and labels helped readers understand the concept being studied as it related to parts of a larger system. The E-GAP instrument (and the GAP instrument from which it was derived), code a graphic's systematicity as being low, medium, or high. A graphic with low systematicity depicts an isolated unit not integrated into a larger system. A graphic deemed having medium systematicity references some aspects of a system, for example the graphic might have labels or arrows demonstrating movement. Graphics with high systematicity would help readers build a mental model of the system; for example the graphic might show three frames of a time series depicting how change occurs over time. The majority of the static graphics analyzed (83.7%) were coded as having low or medium systematicity (See Table 6). Since high school physics is traditionally a challenging course, it would have been good to see publishers include more cognitively-rich graphics to help students understand difficult material.

Table 6

Degree of Systematicity in Static Graphics

Degree of Systematicity	Frequency	Percentage
Low systematicity	109	50.7
Medium systematicity	71	33.0
High systematicity	35	16.3
Total	215	100.0

The static graphics were also analyzed to determine how the information in the text and the graphic were related – that is, their semantic relationship. Graphics that added only an affective component and did not support the text with meaning were coded as being decorative only. Those graphics that reinforced and added concreteness to what was presented in the text were coded as being representational. Organizational graphics were those that added coherence by putting information within a greater scheme, for example a scale diagram showing the relative size of objects. Three other coding choices were available to score graphics when they represented what was in the text and also added new information. These choices were C1 (connection level 1) – a graphic that was easy to interpret that added some additional information, C2 (connection level 2) – a graphic that was relatively easy to interpret but the link between the text and graphic would be less concrete, and C3 (connection level 3) – a graphic that required background knowledge and scrutiny to derive its meaning. Most of the graphics (75.8%) were deemed to be representational, that is they reinforced what was presented in the text but did not help the readers develop a mental model of the information by

presenting it as part of a larger system or scheme. None of the graphics analyzed fell into

the C2 or C3 categories (see Table 7 and Figures 8, 9, 10, and 11).

Table 7
Semantic Relationship between Text and Static Graphics

Semantic Relationship	Frequency	Percentage
Decorative	22	10.2
Representational	163	75.8
Organizational	29	13.5
Connection – level 1	1	.5
Connection – level 2	0	0
Connection – level 3	0	0
Total	215	100.0

Sapling Learning, 2014

Figure 8. Example of a decorative graphic.
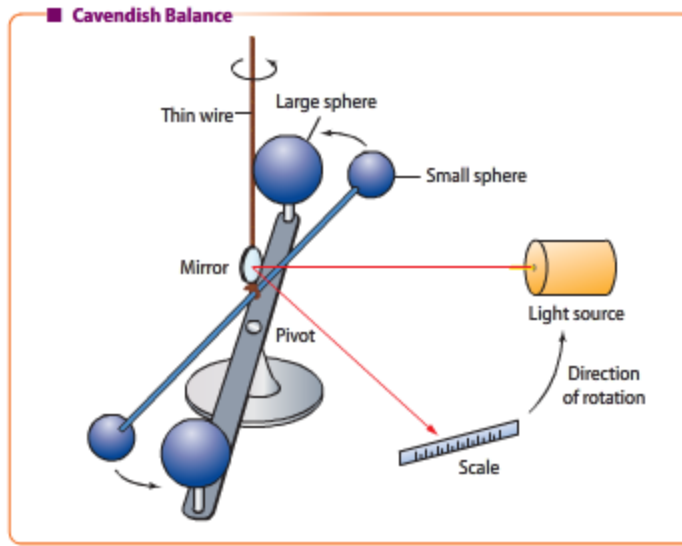
McGraw-Hill, 2015

Figure 9. Example of a representational graphic.
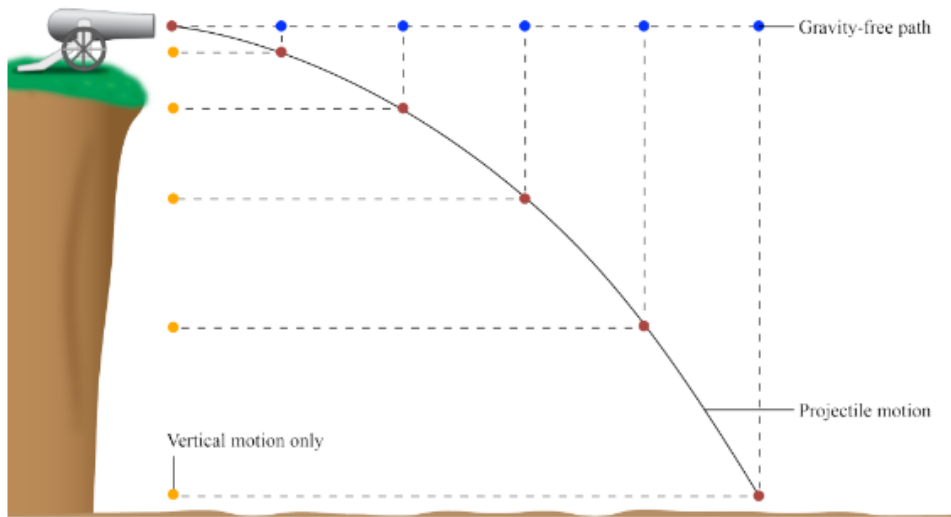
Sapling Learning, 2014

Figure 10. Example of an organizational graphic.

Figure 9 When a bowling ball is dropped, mechanical energy is conserved.

Predict Suppose the ball started with an upward velocity. What would its energy graph look like?

Mechanical Energy
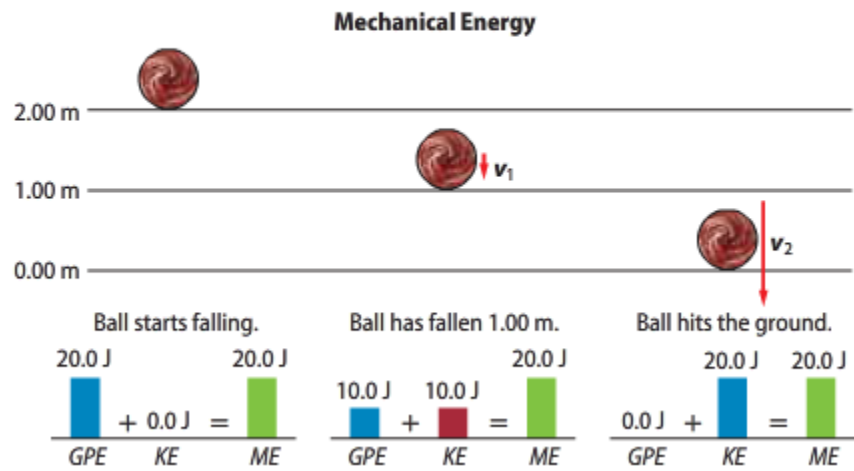
McGraw-Hill, 2015

Figure 11. Example of a connection – level 1 graphic.

Other variables that were coded for the static graphics included spatial contiguity (proximity of graphic and text which is referenced), indexical reference (was there a reference to the graphic in the text), captions (what was the nature of the information in the caption), and color (were the graphics in black and white or color). It was found that the text and graphic were spatially contiguous virtually all of the time (96.3% - see Table 8), most graphics were referenced to in the text (93.5% - see Table 9), and most captions (47.0% - see Table 10) provided a description of the graphic with few details about what was in the textual information. The vast majority of the graphics (96.7% - see Table 11) were in color.

Table 8
Spatial Contiguity between Text and Static Graphics

Spatial Contiguity	Frequency	Percentage
Direct (text and graphic are adjacent)	207	96.3
Proximal (on the same page but not adjacent)	1	.5
Unconnected (no connection between graphic and text)	7	3.3
Total	215	100.0

Table 9
Indexical Reference between Text and Static Graphics

Indexical Reference	Frequency	Percentage
Text references the graphic	201	93.5
Text does not reference the graphic	14	6.5
Total	215	100.0

Table 10
Nature of the Caption Associated with Static Graphics

Nature of the Caption	Frequency	Percentage
No caption	35	16.3
Caption with few details	101	47.0
Details in caption associate graphic to the text	73	34.0
Caption actively engages reader	6	2.8
Total	215	100.0

Table 11

Frequency by Color of Static Graphics

Color	Frequency	Percentage
Color	208	96.7
Black and white	7	3.3
Total	215	100.0

For the multimedia elements the goal of the study was to describe the frequency and nature of the elements and determine how well they adhered to several researched-based principles of multimedia learning including coherence (is extraneous material presented that might distract the learner), redundancy (is text associated with a graphic presented in both auditory and textual format), and temporal contiguity (are corresponding words and graphics presented simultaneously rather than successively). As described previously, one of the resources analyzed contained only static graphics since it was merely a PDF copy of the publisher's traditionally printed textbook (McGraw-Hill, 2015). Another resource contained only two multimedia elements (Sapling Learning, 2014). On the other end of the spectrum were two resources that contained virtually no static graphics, only multimedia elements (ExploreLearning, 2014; Perfection Learning, 2010). The other two resources (Ergopedia, 2014; Houghton Mifflin Harcourt, 2015) analyzed contained a blend of static graphics and multimedia elements (see Table 12).

Table 12
Percentage of Multimedia Element Types by Publisher

	Narration Describing Graphic	Narration Duplicating On-screen Text	Image Map	Animation	Video File	Simulation	Total
Ergopedia	0	0	0	26.3	26.3	47.4	100
ExploreLearning	0	0	0	0	0	100	100
Houg. Miff. Harcourt	44	13.6	10.2	22	0	10.2	100
McGraw-Hill	0	0	0	0	0	0	0
Perfection Learning	0	32.3	0	47.3	0	20.4	100
Sapling Learning	0	0	0	0	0	100.0	100

Five of the six resources were deemed to have multimedia elements with fully coherent presentations devoid of any extraneous elements that might distract the learner from the task at hand. Only one publisher (Ergopedia, 2014) had a multimedia element (a stopwatch/timer utility) that was considered to be non-coherent (see Figure 3). The caption for the graphic told the reader to "use this interactive utility as a stopwatch or countdown timer for investigations and class demonstrations" (Ergopedia, 2014, p. 188) but there were no investigations or demonstrations presented in close proximity in the text for which it would be useful. The relative absence of non-coherence is a notable outcome since the previous study (Anderson & Slough, 2012) of supplemental materials revealed a much higher percentage (9.9%) of non-coherent elements.
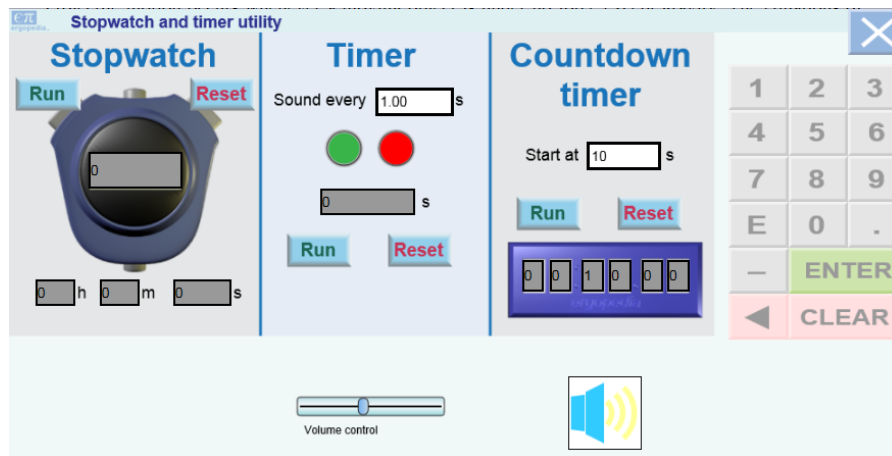
Ergopedia, 2014

Figure 12. Example of a non-coherent multimedia element.

Appropriate temporal contiguity was not a problem for any of the resources, as all narration was presented at the same time as the graphics. Clark and Mayer (2009, 2001) found that students learn better when graphics and narration are presented simultaneously rather than successively, which was the case for all multimedia elements considered in this study. To analyze the redundancy variable the number of graphics with narration duplicating text on the screen was compared to graphics with narration not duplicating text on the screen. It was found that 59.4% of the graphics with narration had redundancy, that is, the narration duplicated the text presented on the screen. Clark and Mayer found that text presented in both auditory and visual formats can overload the cognitive abilities of the brain. Asking students to look at a graphic, read text, and listen to a narration of the same text is asking too much according to studies done by Clark and Mayer.

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Table 13

Redundancy of Narration and Text for Multimedia Elements

Type of Narration	Frequency	Percentage
Narration without textual duplication	26	40.6
Narration duplicates text	38	59.4
Total	64	100.0

CHAPTER IV

SUMMARY AND CONCLUSIONS

The electronic texts analyzed for this study are similar to traditional texts analyzed using the GAP protocol (Slough et al., 2010), in that they have large numbers of high-quality graphics and they do include some of more interactive graphical elements. Interactive graphics seem especially important for science classes where concepts can often be very abstract in nature and difficult to depict in a two-dimensional illustration in a traditional textbook. The integration of animations and simulations, especially those in which the user is able to manipulate variables, could greatly impact student learning in science. The multimedia appeal of online resources is without question, as students are increasingly immersed in a digital world full of animated graphics and video files that can teach them almost anything. Two of the six resources considered in this study contained virtually nothing but this type of graphical element, almost completely leaving behind the domain of static graphics and fully taking advantage of the twenty-first century's rich technological resources.

The resources fared well regarding their adherence to accepted tenets of effective multimedia instruction. There was virtually no extraneous material presented (thus adhering to the coherence variable) in the resources, a positive step towards eliminating the production of teaching materials that attempt to engage students by entertaining them with background music or superfluous video files that only overwhelm short term memory and may lead to poor retention and transfer. When narration was included that described a graphical element it was presented at the same time as the graphic for all the

graphical elements analyzed in the study. Presenting the audio in this manner adheres to Mayer's temporal contiguity principle. A large percentage (59.4%) of the graphics that contained narration duplicated the text on the screen. This goes against Mayer's redundancy principle which suggests that a learner's visual channel may be overwhelmed by studying the graphic and reading the text at the same time.

An interesting question to consider is how Mayer's multimedia redundancy principle would apply to English language learners. Common instructional practices for teachers working with these students include presenting both auditory and written versions of textual material to help with language acquisition. Should instructional materials (and classroom teachers) use this same strategy when graphics are part of the instruction? A recent study (Sombatteera & Kalyuga, 2012) indicates that Mayer's principle might be modified somewhat to assist in language acquisition for students using multimedia materials in their non-native language. The suggested modification would come in the form of key vocabulary words or phrases (instead of the entire passage of text) being presented in printed form as the audio file plays as part of a multimedia element.

Unfortunately some of the electronic resources do not take full advantage of the more interactive graphical elements (including the resource that merely presents PDF files of the traditional text) or they are presented in such a way as to have questionable educational value. Of concern are the digital texts that incorporate multimedia elements in a separate window or screen devoid of any text. Some of the resources have print-based text materials (worksheets, simulation guides, informational handouts, etc.) that

must be printed and referred to while interacting with the visual. This spatial disconnect between text and graphic raises serious concerns about educational/pedagogical value. Will a student be focused enough to pay attention to information in a paper handout while interacting with the visual? What happens to the paper handouts after the lesson is over – will the students keep them in a notebook or discard them? And if paper handouts are necessary, would it not be a more efficient use of resources to have them in a printed and bound fashion (essentially a traditional textbook) that could be reused from year to year? Another resource (Houghton Mifflin Harcourt, 2015) contained numerous multimedia elements, but they were not integrated into the eBook at all. Students using the materials may not even know that they are there as they require navigating through a series of menus to get to them.

Limitations of the Study

This study was designed to characterize the nature of graphical representations in newly adopted electronic physics textbooks to be used in public schools in Texas beginning in the fall of 2014. The outcomes of the study would likely be similar if textbooks for other science courses were analyzed, but perhaps not textbooks in other academic disciplines such as social studies or mathematics. Physics textbooks may have more simulations (graphical elements where users control one or more experimental variables) than books published for biology or chemistry, but conclusions reached about the nature of the graphical elements should be extendable to textbooks produced for other science courses.

The availability of electronic textbooks to be used in K-12 settings is very new, and the type and number of resources will likely change rapidly as more teachers and students use the new resources. The first electronic curriculum materials became available for science teachers in Texas only two years ago (Texas Education Agency, 2011), and those materials were meant to supplement, no supplant, traditional print-based publications. It is anticipated that many more multimedia elements will be included by the publishers in the newly adopted materials than in the previous supplemental adoption analyzed in the pilot study. A limitation of any study of electronic resources is that it will reflect only the nature of the materials as they exist at that time. Electronic delivery of instructional materials facilitates updates and revisions by publishers that are not possible with traditional textbooks having a ten-year adoption cycle.

Recommendations and Future Implications

The six resources reviewed in this study varied greatly in the content and quality of their graphical elements. Perhaps the ideal electronic textbook contains elements of all six – rich multimedia content that remains grounded with textual elements that actively involve the reader, helps build mental models and systems thinking, and adheres to cognitively-based principles of multimedia instruction. With an ever-expanding tablet PC market one can easily predict an exponential number of electronic texts flooding the market and demanding attention. The implications of this for educators at all levels are staggering. Will traditional textbooks really be replaced by digital files on multi-touch tablets? Do schools have enough computers and tablets to take advantage of emerging

online resources? Will students get the educational message from electronic resources, or expect to just be entertained? These questions and others warrant serious consideration before schools jump on the electronic textbook bandwagon. To paraphrase Bette Davis in the movie All About Eve, "fasten your seatbelts, we're in for a bumpy ride!"

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E-GAP Recording Chart
Modified from Graphical Analysis Protocol (GAP) Instrument (Slough, et al., 2010)

Publisher _____

Page Num.	1. Text Struct. (1 - 3)	2. T/R Inter. (1-5)	3. Multi. Prop. (1-3)	Graphic Number	4. Color (1 or 2)	5. Class. Of Graphic (1-13)	6. System. (1-3)	7. Spatial Cont. (1-4)	8. Index. Ref. (1-2)	9. Caption (1-4)	10. Sem. Relat. (1-3 or 4-6)	Multi. Ele. Num.	11. Type (1-8)	12. Temp. Cont. (1-4)	13. Coher. (1-2)

APPENDIX B

E-GAP Instrument
Modified from Graphical Analysis Protocol (GAP) Instrument (Slough, et al., 2010)

Working Definitions & Codes

Part I: Text (at the page level)

1. Text Structure

1   There is no text or limited text (e.g., labels) on the page.

2   Linear – the text moves from left to right and top to bottom.

3   Non-linear – the text direction is web-like or circular in organization.

2. Text/Reader Interaction

1   There is no text or limited text on the page.

2   Informational/passive voice, transmission model.

3   The text uses the second person (i.e., you) occasionally to sound as if it is speaking to the reader.

4   The text encourages active reading by requesting that the participant makes predictions, have reactions or poses questions.

5   The text encourages the reader to actively participate (e.g., "Put your hand on your head").

3. Multimedia Proportion
Looking at one page the coders will determine if:

1   Graphics > Text

2   Graphics = Text

3   Text > Graphics

Next, consider the individual graphics on each page. If a traditional "static" graphic is presented continue to part II. To code a multimedia element skip to Part IV.
Note about numbering - In the case of multiple graphics, each graphic will be given a page number and a letter (e.g., 4a, 4b etc.). The numbering will start at the top left of the page and continue clockwise.

Part II: Static Graphics

4. Color

1   Color

2   Black & White

5. Classification of Graphic

1   Photograph

2   Naturalistic Drawing - all the features of the subject are depicted in detail.

3   Stylized Drawing - graphics are delineated only with their outlines or in symbolic drawing.

4   Picture Glossary - parts of the pictures are named with labels.

5   Scale Diagram - A scale is displayed beside the subject for indicating its size, temperature, distance, etc.

6   Flow Chart – cycle arrows or numbers are marked among stages in a circular process.

7   Flow Chart – sequence - arrows or numbers are marked to indicate the stages in a linear process.

8   Cut-away/Cross Section - internal parts or process are marked with labels.

9   Tables - Tables are composed of cells, which are the products of rows and columns.

10   Graphs/Histograms - quantity information is recomposed in the format of relative graphs.

12   3-Dimensional graphic - objects have a sense of volume.

13   Hybrids - Two or more graphics mentioned above are involved.

6. Systematicity – also consider the words in labels/captions.

1   Low – the graphic depicts an isolated unit, not integrated into a larger system. For example, labels the parts of a machine but not how the parts move.

2   Medium – the graphic depicts some aspect of the system. For example, there are arrows or labels that demonstrate movement, but there is not a "before" and "after".

3   High – the graphic would help viewers build a mental model of a system. For example, the graphic shows 3 frames of a time series depicting how change occurs over time.

Part III: INTEGRATION

7. Spatial Contiguity - What is the spatial relationship between the graphic and text that supports it?

1   Direct – the graphic and text are adjacent.

2   Proximal – on the same page but not adjacent.

3   Distal – on different pages (the reader must click to another page to see the graphic).

4   Unconnected - there is no connection between the text and a graphic.

8. Indexical Reference

1   Text references the graphics (e.g., See Figure 1).

2   Text does not reference the graphic.

9. Captions

1   No caption

2   Caption identifies the target of the graphic but does not provide details.

3   Caption provides a description of the graphic with details and associates the graphic to the main text.

4   Caption actively engages viewer (e.g., asks a question, poses a task).

10. Semantic Relations - how the information in the text and graphic are related.

1   Decorative – adds affective component, does not support text with meaning.

2   Representational – directly shows what was in the text (adds concreteness).

3   Organizational – adds coherence by putting the information within a greater scheme (e.g., a scale diagram compares relative size).

CONNECTION - represents the information in the text AND adds new information. The reader may need to make connections to text. The reader may also need to use global information needed to make inference on how to interpret the image and link it to the text.

4   C1 - An image with a score of C1 would be easy to interpret and add some additional information that would clearly link to the text.

5   C2 - An image with a score of C2 would be relatively easy to interpret, but the link between the text and the new information would be less concrete. For example, the caption could use different verbiage.

6   C3 - An image with a score of C3 would add new information, but the image would require background knowledge and scrutiny to derive its meaning.

Part IV: Multimedia Elements

11. Types of Multimedia Elements

1 Page has audio file with background music.

2 Narration is included describing a graphical element (no text duplication).

3 Narration is included, but does not describe a graphical element.

4 Narration is included describing a graphical element, and it duplicates text presented on the screen.

5 Image map - illustration with interactivity (mouse-overs provide hyperlinks, sound effects, or information delivery).

6 Animation – successive images creating an illusion of movement

7 Video file

8 Simulation – user is able to manipulate variables of the system

12. Temporal Contiguity - corresponding narration and graphics are presented:

1 No narration is included

2 At the same time

3 Successively

4 User controls when narration plays

13. Coherence

1 No extraneous material is presented with the graphic that might be distracting to user

2 Extraneous material (sounds, visual effects, etc.) is presented with instructional material that might be distracting to the user and does not add to the instruction