Brigham Young University
BYU ScholarsArchive

All Theses and Dissertations

2008-11-13

Comprehension and Retention: The Effect of Concrete Details and Causal Structure in Scientific Narrative

Wendi Michelle Wilcken
Brigham Young University - Provo

Follow this and additional works at: https://scholarsarchive.byu.edu/etd

Part of the Educational Psychology Commons

BYU ScholarsArchive Citation
Wilcken, Wendi Michelle, "Comprehension and Retention: The Effect of Concrete Details and Causal Structure in Scientific Narrative" (2008). *All Theses and Dissertations*. 1650.
https://scholarsarchive.byu.edu/etd/1650

This Dissertation is brought to you for free and open access by BYU ScholarsArchive. It has been accepted for inclusion in All Theses and Dissertations by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.

COMPREHENSION AND RETENTION: THE EFFECT OF CONCRETE DETAILS AND CAUSAL STRUCTURE IN SCIENTIFIC NARRATIVE

By

Wendi M. Wilcken

A dissertation submitted to the faculty of

Brigham Young University

In partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Instructional Psychology and Technology

Brigham Young University

November 13, 2008

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

Wendi M. Wilcken

This dissertation has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

Date	Andrew Gibbons, Chair
Date	Paul Merrill
Date	Richard Sudweeks
Date	Stephen Yanchar
Date	Charles Graham

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the dissertation of Wendi Wilcken in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

____________________________ ____________________________

Date

Andrew Gibbons
Chair, Graduate Committee

Accepted for the Department

____________________________ ____________________________

Date

Andrew Gibbons, Department Chair

Accepted for the College

____________________________ ____________________________

Date

K. Richard Young, Dean

ABSTRACT

COMPREHENSION AND RETENTION: THE EFFECT OF CONCRETE DETAILS AND CAUSAL STRUCTURE IN SCIENTIFIC NARRATIVE

Wendi M. Wilcken

Department of Instructional Psychology and Technology

Doctor of Philosophy

The purpose of this study was to examine two of the salient elements of instructional narratives as a guide to instructional practice. The literature summarized in this report discusses the theoretical basis for narrative impact on comprehension and retention, enumerates and defines possible salient narrative elements from the literature, and examines the instructional impact of two of these elements: concrete details and causal structure. This is intended to help provide guidance to instructional designers and teachers who desire to use narrative in science instruction. Participants included 94 high school physics students. An experimental research design of 2 (Gender) x 2 (Concreteness) x 2 (Causal Structure) x 2 (Comprehension as within-subjects) ANCOVA was used to analyze the effects of the narrative elements. It was found that concrete details improved comprehension and retention but that causal structure had no statistically significant impact on comprehension or retention. There were no significant

gender differences in comprehension or retention though there were two- and three-way interactions between the independent variables.

ACKNOWLEDGEMENTS

I would like to thank my committee for their guidance, expertise and feedback. Thank you to the physics teachers who contributed their knowledge and class time to this research. A special thank you to my husband, Jordan, and to my children, Jordy and Hannah, for their loving support and encouragement. And thank you to my Heavenly Father who blessed me with the capacity and resources to complete this dissertation while caring for my young and growing family.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

"Until science is mixed with emotion, and appeals to the heart and imagination, it is like dead inorganic matter; and when it becomes so mixed and so transformed it is literature." (John Burroughs, 1889 as cited in Campbell, 1998)

Physics instruction in the United States has a problem: many students do not comprehend or retain much of what they have been taught in their physics classes. Redish & Steinberg (1999) assert that “Many physics faculty come away from teaching introductory physics deeply dismayed with how little the majority of their students have learned” (p. 24). Hestenes (1987) furthers this sentiment by stating that the “generally unsatisfactory outcome of instruction in introductory physics is too familiar to require documentation” and that “cognitive research . . . has documented serious deficiencies in traditional physics instruction” (p. 440). The abstract presentation of physics principles requires students to have formalized reasoning skills — something not yet developed in many students.

Scientific thinking and writing in general tends toward abstract, depersonalized, objectified, context-free principles (DiPardo, 1989; Graesser, McNamara & Louwerse, 2002). Physics instruction, for example, is commonly taught as abstract principles and decontextualized rules from textbooks written in expository language and is considered difficult to comprehend (Leal, 1994; Vasquez, 1997). Schank (1990) describes why abstract principles are difficult for many people to understand:

> We understand events in terms of events we have already understood. When a decision-making heuristic, or rule of thumb, is presented to us without a context, we cannot decide the validity of the rule we have heard, nor do we know where to

> store this rule in our memories. Thus, what we are presented is both difficult to evaluate and difficult to remember, making it virtually useless. (p. 15)

Edelson (1993) claims that “in most public schools, math and science are still taught as the memorization of formulas and algorithms, and our failure to compete with the rest of the world in these areas is now considered a national crisis” (p. 49).

Typical math and science instruction requires the student to have formalized reasoning skills. This presents a problem, however, because Shayer and Williams (1978 as cited in Stannard, 2001) found that a large percentage of the population doesn’t reach formal operations. Physics professor, Russell Stannard, and other science instructors assert that physics instruction should follow a concrete approach which gives the students a context they can relate to instead of a formal approach as it is now taught (Stannard, 2001).

Science instructors and researchers are currently searching for ways to attract more students to the sciences, improve their comprehension and retention of scientific principles, and improve their national science testing results. There have been major curriculum reforms in recent years in an attempt to address these problems (e.g. “physics first” and “delete the textbook”) (Graesser, Leon & Otero, 2002).

As part of this reformation, a number of science educators have called for more narrative in science instruction (Folino, 2001; Martin & Brouwer, 1991; Martin & Miller, 1988; Solomon, Scott & Duveen, 1996; Wilson, 2002) considering narrative text to be easy to understand, given its many similarities to everyday life and concrete approach (Graesser, Leon & Otero, 2002).

Teaching with narratives has been considered an effective teaching method in a number of subjects including art (Hendrickson, 1999), religion (Cook, 2000), business (Hernandez-Serrano, et al., 2003), nursing (Yoder-Wise & Kowalski, 2003) and social studies (Estes & Vasquez-Levy, 2001). Narrative text is considered to be a powerful teaching tool because of its close relation to how people learn from everyday experience. Polkinghorne (1988) tells us that narrative is the means by which “human beings give meaning to their experience . . . [and] functions to give form to the understanding of a purpose of life” (p. 11). Bruner (2002) identifies a “narrative precocity in children” (p. 32), and elaborates that we have “some predisposition, some core knowledge about narrative from the start” (p. 33). These narratives “become templates for experience” (p. 34). Schank (2002) furthers this idea by proposing that our knowledge is largely constructed of narratives, or stories, and that we, from childhood, tell stories to show what we think and know. Stories are didactic in nature (Schank, 2002) and help us learn from experiences—our own and others’ (Schank, 1990).

Narrative discourse capitalizes on the use of context and its close correspondence to everyday language and experience (Graesser, McNamara & Louwerse, 2002). The rich, descriptive style (Green & Brock, 2002) of narrative makes it more easily remembered and understood (Schank, 2002). A narrative has a setting wherein agent(s) pursue goals. This pursuit gives rise to a causal chain of events, prompting emotional reactions and conflicts between agents (Graesser, Olde & Klettke, 2002). The pursuit of goals and the subsequent obstacles or expectations failures build tension or suspense (Green & Brock, 2002). Forms of narrative discourse include stories, folktales, and everyday scripts among others (Graesser, Leon & Otero, 2002).

In response to the call for more narrative in science instruction, there have been a number of narratives written for the express purpose of teaching science. *Quest Atlantis*, *Model It*, *The Jasper Woodbury Series*, and *The Magic School Bus Series* are just a few examples. While these stories proliferate, some educators call for research into the narrative effect (i.e. improved comprehension, interest and memory) in science instruction before moving away from expository text (Norris et al., 2005).

Although the theory presented in this paper suggests that narrative should have a strong instructional impact, a greater part of the research in the area of narrative impact yields equivocal results because of three problems (a) a focus on comparing narrative and expository text, (b) the failure to control for passage content and difficulty while employing great variability in methods and procedures, and (c) the use of varying degrees of narrativity.

First, a number of studies have compared expository and narrative texts in an attempt to show comprehension and retention differences. While this comparison would seem to be obvious at the outset, it has been described as “a horse race between a draft horse and a pony” (R. Sudweeks, personal conversation, February 2006), with much riding on which of the horses is more fit for the assigned task. Indeed, Norris, Guilbert, Smith, Hakimelahi, and Phillips (2005) argued that “comparing pure narrative and pure expository with the same content and difficulty while keeping all other text variables as well as reader, activity, and context variables controlled . . . would be virtually impossible to implement . . . [and that] the finding of a narrative effect in this controlled situation could not be expected to hold in uncontrolled context where all the other text, reader, activity and context variables would immediately come into play” (p. 19).

Second, the studies in the field of discourse psychology and education comparing the two text types employ great variability in methods and procedures, often failing to control for passage content and difficulty. Hence, published studies show effect for either text type or no effect at all. These confounding factors make it difficult to tease out any narrative effect.

Third, the narrativity of the passages, or the narrative *elements*, found in the passages, vary widely. An example of varying degrees of narrativity is found in Hartley's (1986) study in which the narrative was derived from the expository text. He acknowledges that deriving the narrative text in this manner may lead to a comparison of "good" essays and "bad" stories (p. 156). Another study by Bonitatibus and Beal (1996) changed the expository text into a narrative text by naming the bird mentioned in the text. Creating a narrative in this manner results in a narrative lacking many of the features commonly found in narratives. These may be called hybrid texts. "Hybrid" (Norris et al., 2005) or "grey genre" (Leal, 1993) texts can be described as somewhere in the middle of a genre continuum and containing some narrative elements and some elements of expository or argumentation text. These hybrid texts highlight the importance of investigating the effect of narrative features individually.

Norris et al. (2005) point out that "the question remains whether some [narrative] elements are more important than others" (p. 10). Put another way, researchers aren't sure which narrative elements have an impact on comprehension and retention. Until we understand which narrative elements have an instructional impact, science narratives are likely to have results as equivocal as those shown in past studies.

Research Purpose

Seeing the need for focused research in this area, Norris et al. (2005) have developed a theoretical framework for narrative explanation in science and have proposed three research questions for future study:

1. What are the implications of any narrative effect for teaching science?
2. What features of narrative prove through empirical research to be most crucial, and how do they operate? Are there degrees of narrativity associated with degrees of narrative effectiveness?
3. In addition to the possibly beneficial effects of using narrative explanations intrinsic to science, are there positive effects that accrue from the use of narrative explanations extrinsic to science as has been suggested going back many decades? (pp. 25-26)

The present study focuses on the second question, specifically looking into the features, or elements, of narrative prose; leaving the first and third question to researchers interested in curriculum planning. The second question is of interest to the researcher because of its value in guiding instructional design. With more instructors and instructional designers seeking to use narrative to enhance their science teaching, the discovery of principles to guide this practice would be beneficial, promoting narratives that effectively enhance comprehension and retention. This is especially important when teaching a difficult topic like Einstein's Special Theory of Relativity which many students have difficulty comprehending. Meanwhile, until we understand which narrative elements have an instructional impact, use of science narratives are likely to have equivocal results as is shown in past studies.

While there have been no empirical studies to date to determine which of the narrative elements is essential for instructional impact, a number of authors have defined narrative and several have listed the elements believed to have the greatest impact (Graesser et al., 2002; Norris et al., 2005; Schank & Berman, 2002). Table 1 shows an overview of the narrative elements which will be discussed in detail in the next chapter.

Building on the theoretical work of these researchers and others, this study is an attempt to provide a partial answer to the instructional design question: “Which narrative elements impact comprehension and retention?”

This partial answer will be obtained by first, exploring what is known about each of the elements and their narrative impact, and then, choosing two of the narrative elements and researching their instructional impact within a scientific narrative. Analyzing the effect of two elements on reader comprehension and retention will begin to inform the question of which narrative elements have an instructional impact and provide a springboard for studies into other narrative elements.

Although the question of how the narrative elements operate is outside the scope of this paper, theory and research relating to each element will be presented. The present study may also provide a foundation for research into the question of the degrees of narrativity and offer information as guidance into the practice of instructional designers and teachers.

Table 1

Comparison of Narrative Elements

	Theorists		
Narrative Elements	Schank & Berman	Norris et al.	Graesser et al.
Purpose	Themes	Purpose & Narrator	Thematic Point
Spatial Settings and Context		Event-tokens	Spatial settings
Agentive Characters	Hero figure you can relate to	Agency	Agents in pursuit of goals
Goals	Goals		Goals
Obstacles	Expectations, expectation failures/ obstacles	Structure	Obstacles, conflicts between characters, emotional reactions of characters
Explanation	Explanations or solutions (sometimes)	Explanation	
Causal Structure	Plans	Event-tokens	Causal chain of events
Reader		Reader	
Past Time		Past time	
Narrative Appetite		Narrative Appetite	
Concrete Details	Rich details		

Causal structure and concrete details were chosen in this study for research into the instructional impact of narrative elements. These two elements are hypothesized to be critical to narrative instruction for the sciences. Causal structure is a salient element in both narrative (Graesser et al., 2002; Norris et al., 2005) and science instruction (Leon & Penalba, 2002). Concrete details are believed to have an impact on the comprehension and retention of several different kinds of texts (Sadoski, Goetz & Rodriguez, 2000) but scientific narrative has yet to be studied. The next two paragraphs will briefly introduce the two narrative elements chosen for this study. The literature review chapter contains a more in-depth discussion, as well as examples, of these elements and the others listed in Table 1.

For this study, causal structure is defined as the ordering of cause and effect information within the scientific narrative. A *common* causal structure presents the causal information before the effect information. An *inverted* causal structure presents the effect information before the causal information. While narratives commonly present information in a common (cause - effect) order (Long, Poppy & Seely, 1997, cited in Leon & Penalba, 2002), science instruction often presents information in an inverted (effect – cause) order (Leon & Penalba, 2002).

Because novices are thought to build cause-effect mental models (Leon & Penalba, 2002), a cause-effect order may facilitate comprehension and retention. It remains uncertain what the effect of ordering on comprehension and retention might be, although as a possible clue, reading times for narratives presented in a cause-effect order were shorter than those presented in an effect-cause order (Viol, 1984).

On the other hand, Graesser, Olde and Klettke (2002) contend that “why?” questions drive comprehension. The question arises if presenting the scientific information in an effect-cause ordering may prompt the reader to pose “why?” questions more than a cause-effect ordering, thus promoting better comprehension. Besides this, presenting physics instruction in an effect-cause manner is thought to facilitate comprehension by reducing the need for formalized thinking (Stannard, 2001).

Research into the causal structure of a scientific narrative could shed some light on the question of which ordering (common or inverted) promotes better comprehension and retention.

Concrete details in this study are defined as details “that can be perceived by the senses; real; actual” (Neufeldt & Guralink, p. 289) and which readily invoke mental images (Sadoski, Goetz, & Fritz, 1993). Concrete details may refer to a material object, or one that brings to memory a sensory experience such as a taste or smell. *Abstract* is defined as “thought of apart from any particular instances or material objects; not concrete” (Neufeldt & Guralink, p. 5). Sadoski, Goetz and Rodriguez (2000) illustrate concreteness with the phrase *a juicy hot dog* which “may activate visual and perhaps taste images of frankfurters in buns, perhaps covered with condiments” (p. 85).

It is hypothesized that the use of concrete detail in narrative explanations will improve both comprehension and retention through a close correspondence to everyday experiences (Chambliss, 2002) and by increasing encoding through imagery (Driscoll, 2000). Clark & Paivio’s (1991) duel coding theory suggests that concrete details may be encoded both verbally and nonverbally, resulting in improved comprehension through elaboration and improved recall through redundancy.

The effect of concrete details may be influenced by text types. Sadoski et al. (2000) found that concreteness in science and math expository texts had less effect on recall than in its persuasive and literary text counterparts. This difference, they speculate, may come from the abstract principles that math and science texts inevitably present but pointed out that the persuasive and literary texts also dealt with abstract concepts.

With the appeal of Sadoski et al. (2000) for more research into the effect of concreteness on different text types, there appears to be a place in the literature for research on the yet unstudied scientific narrative.

Gender differences in the comprehension and retention of scientific narrative will also be examined. Males tend to achieve better in science than females (Mau & Lynn, 2000) especially in physics (Johnson & Murphy, 1986 as cited in Tamir 1988; Tamir, 1988). In addition, boys were found to be better able to apply physics concepts (Tamir, 1988) and performed better in inquiry-based physics courses (Cavallo et al. 2004).

Narrative elements may mediate these gender differences. A main character that the reader can relate to increases the narrative impact (Graesser et al. 2002, Schank & Berman, 2002). For example, Azencot & Blum (1985) found that males had a significantly higher affect score when reading a narrative with a male character. The main character in the narrative presented in this study is a female which may increase female comprehension and retention scores.

The concrete nature of the narratives may mediate the differences as well. Although a higher conceptual understanding of physics was associated with being male, it was also associated with higher levels of visualization ability (Damas, 1994).

Research Hypotheses

The presence of either narrative element or the combination of the two in an instructional science narrative could impact reader comprehension and retention. Improved comprehension and retention in the sciences through the effective use of these two narrative elements could have widespread benefits.

Narrative effect for concrete details and causal structure will be based on the following predicted results:

1. Students reading the scientific narrative with explanations that include concrete detail will receive higher mean scores for comprehension and retention than students reading the same instruction with explanations that include only abstract details.
2. Students reading the scientific narrative with a common causal structure will receive higher mean scores for comprehension and retention than students reading the same instruction with an inverted causal structure.
3. Students reading the scientific narrative with a combination of common causal structure and concrete detail will receive higher mean scores for comprehension and retention than students reading the same instruction with only a common causal structure or concrete details.
4. Differences in male and female students' mean scores for comprehension and retention will not be statistically significant.

Chapter 2: Literature Review and Conceptual Context

This section will review studies that have compared narrative and expository texts, emphasizing those in science instruction; introduce three theories of narrative impact; and discuss the narrative elements and research related to their use. Finally, gender differences in the study of physics will be examined.

Overall, there is some evidence for a narrative effect on comprehension and retention (Norris et al., 2005). In the field of discourse psychology, for example, there have been a number of studies that show that the narrative format aids in the comprehension of a text (Blake, 1985; Bonitatibus & Beal, 1996; Tun, 1989; Zabrucky & Moore, 1999). There are also studies which show that narrative text helps students retain what they have read (Lucas, 1981; Petros et al., 1989; Tun, 1989; Zabrucky & Moore, 1999; Zabrucky & Ratner, 1992). In retention, however, age does seem to make a difference. In a meta-analysis, Zelinski and Gilewski (1988) found that as people age they are able to retain expository text more easily than narrative text. Overall, it is important to note that these studies employed great variability in methods and procedures. Varying degrees of narrativity and narrative elements were present in their materials and many studies failed to control for passage content and difficulty.

In science instruction there are few studies researching the comprehension and retention effects of narrative text. As with those found generally, these studies also show varying results. An important difference in these studies, compared to those previously mentioned, is that they control for content and, presumably, text difficulty. Three studies found narrative to aid in comprehension (Azencot & Blum, 1985; Leal, 1994; Maria & Johnson, 1990). Another study found that expository text was more helpful to students' comprehension (Alvermann, Hynd & Qian, 1995), while the last found no effect for text type (Maria & Junge, 1993). When looking at retention, two studies found that students were able to recall information presented in narrative text more easily than expository (Leal, 1994; Maria & Johnson, 1990). The third study found no difference for text type (Maria & Junge, 1993). The following paragraphs provide more detailed information about each of the studies.

In Azencot and Blum's (1985) study on comprehension, seventh and eighth graders were grouped so that one group studied a biology text and the story *The Rose Detective,* while the other group studied only the biology text. Azencot and Blum found that students who had the narrative as well as the expository text performed significantly better on the tests. Leal (1994) found that third graders learned more facts from informational storybooks than from non-fiction texts with the same content. Maria and Johnson (1990, as cited in Maria & Junge, 1993) studied the effects of narrative and expository text on 5th and 7th graders. They found that students reading the narrative text learned the cause of seasons better than those reading the expository text.

Alvermann, Hynd and Qian (1995) used a narrative text or an expository text to teach a biology concept to 9th graders. While student test scores were comparable overall, students reading the expository material performed significantly better on application and short answer questions on the posttest.

In Maria and Junge's (1993) study, 5th graders read either *The Magic Schoolbus Inside the Earth* or a section of a chapter from a fourth-grade science textbook with the same concepts. Maria and Junge found no comprehension difference for text type.

When looking at retention, Leal's (1994) study found that 3rd graders remembered more facts from informational storybooks than from expository texts when tested immediately after the reading and again six weeks later. Maria and Johnson's study (1990, as discussed in Leal, 1993) showed that 5th and 7th graders studying seasonal change had better recall with a narrative approach.

Maria and Junge's (1993) study of fifth graders found a difference in recall between good and poor readers, but no recall difference was found for text type.

This review shows that although there is some evidence that a narrative form could be helpful to comprehension and retention, problems such as the variability in methods and procedures, and varying degrees of narrativity and narrative elements used confound efforts to isolate the factors responsible.

Three Theories of Narrative Impact

In an effort to identify the narrative elements responsible for the narrative effect seen in some of the studies above, three theories of narrative impact – those of Schank and Berman (2002), Graesser, Olde and Klettke (2002) and Norris, Guilbert, Smith, Hakimelahi, and Phillips (2005) — have been identified and will provide the foundation for this study. Table 1 in the previous chapter shows an overview comparison of the three theories.

An overview of each of the theories will be followed by a closer look at the elements individually. Each element will be defined in the context of the three competing theories and exemplified. Available published studies relating to comprehension and retention for the narrative element will then be reviewed.

Schank and Berman (2002) defines story as “a structured, coherent retelling of an experience or a fictional account of an experience [including these elements:] themes, goals, plans, expectations, expectation failures (or obstacles), and perhaps, explanations or solutions (p. 288).” Schank and Berman (2002) go on to list the reasons why narratives have an impact on the reader: story details provide opportunity for indexing in memory, stories are didactic in nature, stories often contain surprises or expectation failures that help the reader adjust their mental models, and stories are the building blocks of much of an individual’s current knowledge. To assure that the narrative has an impact, the storyteller/ instructor should engage the interest of the reader, help them gain a frame of reference to relate to the story, time the presentation so that the reader wants or needs the information, give rich detail and context, and present the hero in such a way that the reader can see themselves as the hero.

Graesser et al.’s (2002) fusion facilitation hypothesis bridges with this last idea in that narrative recall is best when the narrator role is fused with the agent role in the story. According to this theory, the reader can best relate to a narrative written in second person, followed next by a first person narrative, then a third person narrative. He defines narrative as a microworld containing a thematic point, goals, obstacles, conflicts between characters, emotional reactions of characters, spatial settings, agents in pursuit of goals, and a causal chain of events. Narrative’s impact comes from a close correspondence to everyday language. Readers develop “why?” questions as they read that drive their comprehension. Narrative may also provide the reader with more vivid mental images and a more elegant conceptual structure.

Norris et al. (2005) lay a theoretical foundation for the use of narrative explanation in science. Their broad review of literature revealed the following narrative elements: event-tokens, past time, agency, narrator, narrative appetite, structure, purpose, and reader. Of the elements listed, they consider event-tokens, past time, and agency the most important.

Narrative Elements

In order to better understand the concepts named by each of the authors, this section discusses each of the named elements and provides examples of them in a science narrative. Where available, findings relating the narrative elements to comprehension and retention — the ability to retain what has been learned and recall information at the appropriate time — will also be discussed.

Purpose. Norris et al. (2005) assign the task of determining the purpose of the story to the narrator. Schank and Berman (2002) use the term "themes" to name the overall lesson to be learned from the story. The narrator is also responsible to select the events and the sequence of events to create a "significant whole" that gives understanding of the world and helps us "imagine and feel the experience of others" (p. 11). Graesser et al.'s (2002) thematic point is the "moral, adage, or main message" (p. 235) emerging from the plot and is said to strongly influence the comprehension and retention of a narrative when properly identified.

An example of an author selecting a purpose for his narrative is found in Gamow's (1965) preface to *Mr. Tompkins in Paperback.* He tells us that the purpose of his narrative is to explain the basic ideas of physics to the layman.

Spatial settings and context. Graesser et al.'s spatial setting gives the story somewhere to happen. Norris et al. (2005) include this idea in their event-tokens as a particular place and time for an event to happen. While Graesser et al. (2002) and Norris et al. (2005) include the idea of spatial settings as a narrative element, Schank and Berman (2002) do not.

The following example from Ian Stewart's (2001) *Flatterland* illustrates setting in a science narrative:

> The house was dowdy and unfashionably pentagonal, but in an excellent location: just along the street from the Palace of the Prefect. It had been in the Square family for almost 150 years, and was now beginning to show its age. Nonetheless, it was a comfortable dwelling, with the typical large Flatlandish entrance hall, seven rooms for the male members of the household, two apartments for the females, a study, a large room that once had housed servants but was now used as a kitchen, with a dining alcove, and a musty cluttered cellar. It had separate doors for women and men – for safety reasons, women being rather sharp if encountered end-on. In the hall a middle-aged woman swept up after her two untidy square sons and her neat and lineal daughter, waving her body from side to side so that the males wouldn't accidentally blunder into an endpoint and cut themselves. She found it a comfortable life, though hardly a fulfilling one, and on the whole she was content with her lot.
>
> In the cellar, her daughter Victoria was anything but content with hers. (p. 1-2)

Spatial settings and context aid comprehension in three ways: they provide a context that allows for the retrieval of prior knowledge (Schank, 1990), they help the reader make appropriate connections that make the information useful (Schank, 1990), and they support case-based reasoning (Edelson, 1993; Schank, Kass & Riesbeck, 1994).

Contextualized information activates prior knowledge (Schank, 1990). As new information is processed and indexed, prior knowledge related to those indices is triggered. When we hear a new story, we remember similar stories and experiences, and we can compare and contrast the new information. The stories and experiences we already possess help us make sense of new information and/or find solutions to current problems (Schank & Berman, 2002).

In contrast, abstract principles are difficult for many people to understand. Schank (1990) explains why this is the case in the following passage:

> We understand events in terms of events we have already understood. When a decision-making heuristic, or rule of thumb, is presented to us without a context, we cannot decide the validity of the rule we have heard, nor do we know where to store this rule in our memories. Thus, what we are presented is both difficult to evaluate and difficult to remember, making it virtually useless. (p. 15)

It is context that allows the retrieval of prior knowledge and the appropriate connections that make information useful.

Another reason abstract principles are difficult to understand is that they require formalized reasoning. This is problematic because a large percentage of the population doesn't reach formal operations (Shayer & Williams, 1978 as cited in Stannard, 2001), a stage described by Piaget (1981). Physics, for example, is commonly taught as abstract principles and decontextualized rules from textbooks written in expository language and is considered difficult to comprehend (Leal, 1994; Vasquez, 1997). Aside from physics, scientific thinking and writing in general tends toward abstract, depersonalized, objectified, context-free principles (DiPardo, 1989; Graesser, McNamara & Louwerse, 2002). Narratives, in contrast, support case-based reasoning, a more concrete approach that is easier to understand.

Spatial settings and context aid comprehension by supporting case-based reasoning. Case-based reasoning (Schank, Kass & Riesbeck,1994) is a process of explaining an anomaly by searching stored experiences and stories for information that might be relevant, evaluating that information for fit in the current situation and, if the fit is not perfect, adapting it in an attempt to better fit the situation. Once an acceptable explanation is discovered, the mental model is modified. Edelson (1993) describes why case-based reasoning is important in teaching complex subjects:

> If people reasoned from first principles most of the time, then you would naturally teach them by presenting them with the sorts of rules they could use to construct large chains of connected inferences. However, since most subjects worth teaching are too complex for a rule-based approach and case-based reasoning is an important part of the way people deal with these subjects, it is important to teach them in a way that will assist the natural process of case-based reasoning. . . In most public schools, math and science are still taught as the memorization of formulas and algorithms, and our failure to compete with the rest of the world in these areas is now considered a national crisis. (p. 49)

Case-based reasoning highlights the importance of indexing for retrieval and comparison, as well as the effect of prior knowledge in the process.

Spatial setting and context also aid retention by providing opportunities for indexing the information appropriately in memory and generating multiple indexes for the same information.

Stories serve as memory aids (Folino, 2001) because they contain contextualized information. Contextualized information is indexed in a number of places in memory whereas abstract information is difficult to index at all (Schank, 1990; Schank and Berman 2002). Contextualized information comes with many indices that aid in memory storage. Indices can be any number of things: personal attitudes and characteristics, situations, problems, events, settings, solutions, or any number of other details. These details relate to, and combine with, previously stored memories. Information stored in memory can be triggered by any new information relating to the details indexed. Indices allow for retrieval of a group of related information from memory when triggered.

Abstract information, by contrast, lacks the degree of context needed to produce a large number of indices for storage and may not be able to relate to any previously stored information (Schank and Berman, 2002). This inability to relate to other indices makes the information difficult to store in a retrievable format. Readers provided with multiple indices for the same information recall that information more easily (Schank and Berman, 2002).

Agentive characters. Each of the three theories lends a unique perspective to the concept of agentive characters. Although Schank and Berman (2002) do not specifically list agents, we find the idea of agency throughout the other elements listed. His characters attempt to achieve some goal, formalize a plan, trust that their plan will work, encounter obstacles that cause a change in perception and/or a change in plan. Having an agentive figure that the reader can relate to also implies the need for an agentive character in the narrative.

Graesser et al. (2002) specifically list "agents in pursuit of goals" as one of his narrative elements. As agents, his characters have conflicts between themselves and emotional reactions to events. Norris et al. (2005) also specifically list agency in their narrative elements, marking it as one of the most important factors. Their actors cause and experience events, and are responsible for their actions. Unlike Schank and Berman (2002) and Graesser et al. (2002), Norris et al. (2005) defines their actors as "human beings or other moral agents" (p. 11).

For Polkinghorne (1988), narratives get their meaning from "human actions and the events that affect human beings, and not relationships among inanimate objects" (p. 6). Mattingly (1991) agrees that narratives should consist of human actors as agents: "In the narrative, people did things and as a result things changed. In the non-narrative account no actors were identified" (p. 242). These ideas contrast with Abbott (2002) who believes that a narrative can consist of non-human, non-agentive characters.

Abbott (2002) defines both *entities*, those things whose actions and reactions cause events, and *characters,* entities with human characteristics. When stories are about people, animals and animated objects, Abbott says, character is the appropriate term. But when the story is about an atom or "an experiment involving the interaction of chemical elements, or the history of shifting landmasses, or the evolution of planetary systems" (p.

17), it is more appropriate to use the term entities. Entities, rather than characters, are generally found in scientific writing.

The following example of agents in scientific narrative is from Russell Stannard's (1989) *The Time and Space of Uncle Albert.*

> This time he rewound the tape fully.
>
> "There," he said as the picture came up. "That's what it was like before you got going. When the craft was standing still, everything looked normal. It's only as the craft got up speed. . . as it is doing now. . . that everything got squashed. It's definitely not the picture that's at fault. We're looking at a real effect. *The spacecraft actually did get squashed!"*
>
> "But. . ." stammered Gedanken. "That's crazy. I didn't see things looking like that. I really didn't, Uncle. I'd have noticed. . ."
>
> "No, you wouldn't. You wouldn't see any change — because you were also getting squashed yourself. Your eyeball was getting squashed. It changed its shape in the same way as the spacecraft was changing. That's why everything carried on looking perfectly normal to you."
>
> "That's stupid! I don't believe this," declared Gedanken emphatically. "I really don't. I couldn't have been squashed. I *would* have noticed. You can't seriously expect me to believe that I could have been squashed almost flat — and didn't feel a thing. It would have broken every bone in my body, for a start." (p. 48)

There appears to be some evidence in the published literature that agentive characters have an effect on the reader. In a study by Bonitatibus and Beal (1996), second and fourth graders were given the same expository content with one change for the experimental group – the bird in the text was given a name. The researchers reported that providing a proper name for the bird fostered internal processing in the children who could then report a second interpretation for ambiguous text. Azencot and Blum (1985) provided seventh and eighth graders with either a biology text or a biology text and a narrative featuring a male character and tested the affective response and cognitive learning. The male students who read the narrative experienced a significant affective change over their counterparts who read only the biology text. All students who read the narrative text scored significantly higher on the posttest.

Goals. Schank and Berman's (2002) story is about the character's attempt to achieve a goal and how the character does or does not achieve it. Graesser et al. (2002), much like Schank and Berman (2002), discuss agents in pursuit of goals. Norris et al. (2005) do not list goals as an element of narrative. Their actors can cause events, implying that the actors have some sort of goal, even if undefined.

This example of character goals is from *The Magic School Bus: Out of This World:*

> "Welcome, crew of the Magic Space Bus," announced Ms. Frizzle as our old school bus changed into a Space Bus. "Our mission today is to find Dorothy Ann's mysterious space object, follow its path, and if necessary keep it from crashing into Walker Elementary!" (Cole, 1996, p. 5)

Obstacles. Schank and Berman (2002) define "expectations" as a trust that the plan to achieve the goal will work and "expectation failures" as surprises or failures in the plan. These failures, or obstacles (Graesser, Olde & Klettke, 2002), lead to a change of perception, belief, and plan. Norris et al.'s (2005) structure of a narrative introduces this element as well: "narratives typically start with imbalances, introduce complications, and end in success or failure. . . [and are] tied together by satisfying expectations that are established previously" (p. 11).

Emotion, surprise and expectation failures found in narratives make recall easier (Engel, 1999; Schank, 1990; Schank & Berman, 2002) by producing strong indices that are more easily remembered (Schank & Berman, 2002). When what the reader encounters in the story does not meet with expectations or match prior knowledge, the reader experiences "expectation failure" (Schank & Berman, 2002). These expectation failures cause the reader to seek an explanation.

An example of a character's surprise at an expectation failure is found in *The Time and Space of Uncle Albert,* a children's book by Russell Stannard. Gedanken (German for "thought") is putting together a science project by helping her Uncle Albert with his thought experiments. Though these experiments they discover the principles of Einstein's Special Theory of Relativity. The results of the experiments are often contrary to all common sense and give Gedanken ample opportunity for expectation failures. In this example they have just completed an experiment and are looking at the results.

> "Well, it's not what *I* expected," said Gedanken crossly, taking the mug. She made a face when she saw what was in it. "That finishes my project. It's a mess. A total muddly mess. It's *stupid*! Wish I'd never started it."
>
> "Whyever do you say that?"
>
> "It's all right for *you*. How am I supposed to explain *that*? What's Turnip going to say when he reads that my time goes slower than your time, but your

time goes slower than mine? It's crazy. Doesn't make sense. I'll look like a regular idiot."

"But why?"

"Oh, come off it, Uncle. You're not *that* thick. He'll want to know whose time actually went slower — won't he? And what am I going to say?"

"But he can't ask that question."

"Of course he can ask that question!" exclaimed Gedanken, getting more and more upset. "And he *will* ask that question. And what's more, *I* want to know what really happened. Who actually got slowed down and who actually got squashed up? Come on. Answer me that." (pp. 98-100)

Concrete details. Green and Brock (2002) tell us that narrative impact comes from a rich, descriptive style and the imagery that it promotes. Schank and Berman (2002) call for stories with rich detail that help the reader to understand and remember what she has read.

Graesser et al. (2002) wonder about the impact of the narrative style:

It remains somewhat of a mystery why narrative text is so easy to comprehend and remember. Perhaps it is because the content of narrative text has such a close correspondence with everyday experiences. Perhaps it is because the language of oral conversation has a closer similarity to narrative text than other discourse genres. Perhaps it is because there are more vivid mental images, or a more elegant composition of the conceptual structures (p. 240).

Part of the reason that narratives are more easily comprehended and remembered may be an element formed by a statement combining two of Graesser et al.'s (2002) thoughts into this one idea: the relating of everyday experiences that provoke imagery.

Webster's New World Dictionary defines *concrete* as "characterized by things that can be perceived by the senses; real; actual" (p. 289). *Abstract*, by contrast, is defined as "thought of apart from any particular instances or material objects; not concrete" (p. 5). Here are some examples of concrete and abstract science text from a study done by Sadoski, Goetz and Rodriguez (2000):

> Concrete –
>
> Acceleration is the rate at which the velocity of an object changes. As a runner sprints off, his speed accelerates; when an airplane blasts down the runway and passengers lurch backward in their seats, the speed of the plane is accelerating. Acceleration may be negative, as in an automobile when the driver suddenly jams on the brakes.
>
> Abstract –
>
> There are three general principles that form the basis of aerodynamics. First, moving air will push up against a surface placed at an angle to the airflow. Secondly, the force of the air under a moving object will propel it upward; and finally, the surfaces of an object will move toward a rapidly moving airstream above it.

Looking at these two examples, it is easy for the reader to relate to, and even imagine, the everyday experiences referred to in the concrete example and understand the forces being explained. By contrast, it is less easy to visualize and to understand the principles of aerodynamics in the abstract example.

Sadoski, Goetz and Rodriguez (2000) explain that the dual coding theory of cognition (Clark & Paivio, 1991) assumes a “referential connection between concrete language and mental imagery” (p. 87). They illustrate this connection with the concrete phrase *a juicy hot dog* which “may activate visual and perhaps taste images of frankfurters in buns, perhaps covered with condiments” (p. 85).

The reader’s background knowledge influences their comprehension of the text, so the best way to help a diverse readership understand the concepts presented is to “include words, examples, and analogies that touch base with a wide range of everyday experiences” (Chambliss, 2002, p. 56). Everyday experiences are those things we can see, hear, touch and otherwise experience through our senses. A text conveys these everyday ideas through concrete writing.

Relating to prior knowledge is important, but familiarity with the topic is not the only factor in comprehension and retention. Although familiarity with the topic and vocabulary used can effect children’s comprehension (Chambliss, 2002), Graesser, Olde and Klettke (2002) tell us that it is not familiarity that effects recall. Adults are more interested in texts that use examples and analogies that not only connect with their prior knowledge but that also provide vivid details that can be “pictured” (Chambliss, 2002).

Driscoll (2000) tells us that “imagery can be a very effective method of encoding information” (p. 92). Cognitive science and discourse psychology have recognized some limitations to reading comprehension, one of which is a working memory with limited capacity, or the ability to only focus on one or two ideas at a time (Graesser et al., 2002).

Chunking ideas as images and encoding them makes room for the new concepts, principles and vocabulary being introduced in instruction. Clark and Paivio's (1991) duel coding theory suggests that concrete details may be encoded both verbally and nonverbally, resulting in improved comprehension through elaboration and improved recall through redundancy.

Adult readers find texts with details that provoke vivid images to be interesting and are able to recall them more easily (Chambliss, 2002). These vivid mental images are indexes that can serve as a prompt for an entire story at a later time (Green & Brock, 2002). Hidi and Baird (1988) modified a science-biography text to make it more concrete and found that students recalled more of the modified text in both immediate and delayed testing. In a 1993 study, Sadoski et al. also found in both immediate and delayed testing that concrete historical narratives were recalled more than twice as well as their abstract counterparts.

There have been studies that show an effect for concreteness on comprehension and retention, the larger part of them testing social science texts or journalism articles. The following studies used educational materials.

To discover the effect of concreteness on comprehension, Wharton (1980) modified narrative passages from a history textbook to make them more concrete. Students reading the concrete versions of the passages scored significantly higher on comprehension questions. Summing up a series of studies, Graves et al. (1991) concluded that revising history texts to add concreteness, character identification and other engaging content promoted comprehension and recall. In a Sadoski, Goetz and Rodriguez (2000) study using four text types, concreteness was the most effective predictor of comprehensibility, interestingness, and recall in a causal analysis. “The way concreteness exerts its effect in various text types appears to be complex and well deserving of further research” (Sadoski et al., 2000, p. 92). Sadoski et al. (2000) studied four text types (literary, social science narrative (history and social science), expository (science and math) and persuasion) and found that concreteness promoted recall at varying degrees depending on the text type. The recall for expository science and math texts was not effected by concreteness as much as the recall for persuasion and social science narrative. They speculate that this difference may come from the abstract principles that science and math texts inevitably present but are quick to point out that the persuasive and literary texts also dealt with abstract principles and themes.

There have been no studies on scientific narrative and concrete language to this point. The scientific narrative presented in this paper differs from the science biography mentioned above in that it seeks to teach abstract principles in a narrative form. Science biography commonly tells the story of the inventor or the scientist and how their work progressed. A scientific narrative will often not include the scientist at all, simply discussing the principle. With the appeal of Sadoski et al. (2000) for more research into the effect of concreteness on different text types, there appears to be a place in the literature for research on scientific narrative.

This study will focus on the effect of concrete words and phrases in the scientific narrative’s explanations.

Explanation. Schank and Berman (2002) define explanations or solutions as the reason why the expectation failed. While Schank and Berman (2002) say that explanations are only sometimes included in stories and Graesser et al. (2002) do not mention explanations at all, Norris et al.'s (2005) definition that "explanation is . . . an act intended to make something clear, understandable, or intelligible" (p. 12) illustrates that explanations are essential to didactic stories, especially in preventing and correcting misconceptions.

The following example of explanation in scientific narrative is from *The New World of Mr. Tompkins: George Gamow's Classic Mr. Tompkins in Paperback* (1999), revised and updated by Russell Stannard. Gamow's original story about the daydreaming banker Mr. Tompkins, published in 1940, introduced the principles of modern physics to the layperson.

In the excerpt below, we join Mr. Tompkins who has retired to bed after attending a lecture on atomic nuclei. In his dream he will learn about the constituent parts of an atom and their properties, about the strong and weak forces of the nucleus, and about radioactive decay. The woodcarver's explanation is in response to Mr. Tompkins' questions about radioactive decay:

> 'But neutrons are unstable too, aren't they?' asked Mr. Tompkins, remembering the recent demonstration.
>
> 'On their own, yes. But when they're packed tightly in the nucleus, and surrounded by other particles, they become quite stable. Unless,' he added hastily, 'there are too many neutrons in the nucleus – relative to the number of protons. Then they can transform themselves into protons, with the extra paint being emitted from the nucleus in the form of a positive electron. Such adjustments we call beta transformations. "Beta" is the old name given to electrons emitted from such radioactive decays.'

> ‘Do you use any glue, in making the nuclei?’ asked Mr. Tompkins with interest.
>
> ‘Don’t need any,’ answered the old man. ‘These particles, you see, stick to each other by themselves as soon as you bring them into contact. You can try it yourself if you want to.’ Following this advice, Mr. Tompkins took one proton and one neutron in each hand, and brought them together carefully. At once he felt a strong pull, and looking at the particles he noticed an extremely strange phenomenon. The particles were exchanging colour, becoming alternately red and white. It seemed as if the red paint were ‘jumping’ from the ball in his right hand to the one in his left hand, and back again. This twinkling of colour was so fast that the two balls seemed to be connected by a pinkish band along which the colouring was oscillating to and fro.
>
> ‘This is what my friends the theoretical physicists call the “exchange phenomenon”,’ said the old master, chuckling at Mr. Tompkins’s surprise. ‘Both balls want to be red, or to have the electric charge, if you want to put it that way, and as they cannot have it simultaneously they pull it to and fro alternately. Neither want to give it up, and so they stick together until you separate them by force. (pp. 179-180)

Ohlsson (2002) defines explanation as “answers to questions, particularly questions about why an event happened, why something is the case, and how a particular state of affairs came about or why it persists (p. 93).” Schank and Berman (2002) tell us that if an explanation is not provided within the story, the reader will search their memory for a case that could provide an acceptable explanation. The reader's self-contrived explanation may or may not be correct.

The reader's search for explanation plays a vital role in reader comprehension. Comprehension happens as the reader seeks the answer to the question "Why?" (Graesser, Olde & Klettke, 2002) and finds an explanation (Leon and Penalba, 2002). Generating explanations helps the reader comprehend text (Goldman & Bisanz, 2002) and provides the reader with a conceptual framework (Brewer et al., 2000 as quoted in Ohlsson, 2002), which is more elegant in the narrative form (Graesser, Olde & Klettke, 2002).

Explanations are comprised of generative relationships (Ohlsson, 2002) — "relations that attribute the existence of an explanadum to the factor or factors that produced it" (p. 99) – which include cause and effect relationships. Ohlsson gives as an example heat → melting, where the arrow means "instrumental in bringing about" (p. 101). Because explanations are built of these generative relationships, or causal chains (Schank, Kass & Riesbeck, 1994), they cannot be understood if the reader has not already learned the generative relationships used in the explanation. Furthermore, explanations cannot be formulated without these generative relationships. Explanation schemas (Ohlsson, 2002) consist of one or more generative relationships. Scientific explanations are generally more complicated, consisting of a number of generative relations. Students with little prior knowledge benefit from the opportunity to "acquire all of the generative relations before encountering that explanation." (Ohlsson, 2002, p. 125)

Causal structure. Graesser et al. (2002) list causal chain of events as an important part of a narrative. Norris et al.'s (2005) structure and event tokens relate to the idea of a causal structure. Structure is composed of two independent time sequences: plot events and the sequence in which they are related to the reader. Event-tokens are "particular occurrences involving particular actors at a particular place and time [which are] chronologically related [. . ,] interconnected [. . , and which] lead to changes in state [. . , in which] later events [are] seen as significant in light of earlier events" (p. 11). Similarly, Schank and Berman (2002) define their concept "plans" as the set of actions to achieve a goal with results and consequences.

Actions, along with their consequences, are the temporal and causal connections in narrative text. These connections aid comprehension through familiarity and predictability (Zabrucky & Moore, 1999). The strength and number of causal connections determines how well students comprehend text (Leon and Penalba, 2002).

In order to understand an explanation in a text, a student needs to understand each of the generative relationships that build the explanation schema (Ohlsson, 2002). Leon and Penalba (2002) found that novice practitioners, and people in general, build cause-effect mental models, while expert practitioners build effect - cause mental models.

Narrative text is easier for the student to comprehend because it generally presents the information in a cause-effect order (Long, Oppy & Seely, 1997, cited in Leon and Penalba, 2002). A noteworthy exception in the genre is mysteries where the reader encounters the effect before the cause. Like mysteries, scientific text also commonly presents information in an effect-cause order (Leon & Penalba, 2002). This presentation order is said to increase the processing time and difficulty of the text for the reader (Chambliss, 2002; Leon & Penalba, 2002). In contrast, Stannard (2001) promotes teaching Einstein's theory of relativity by presenting the more concrete relativistic effects before stating the two axioms which cause those effects. This method, he says, allows the student who has not yet reached formal operations to comprehend the information more easily.

The Quicksand Book by Tomie dePaola (1977) is an example of a science narrative employing a cause-effect explanation. In this book, you see Jungle Girl swinging on a rope when suddenly her rope breaks, landing her in quicksand. As she calls for help, Jungle Boy appears on the scene. Seeing he has a captive audience, Jungle Boy begins telling her all about the how, when, why and where of quicksand while she sinks deeper and deeper. He finally does rescue her and then trips and falls into the quicksand himself. He calls for help and Jungle Girl reminds him of the techniques he just taught her while she relaxes on safe ground.

> "Help!"
>
> "Hello, Jungle Girl. My goodness, you look very unhappy. Is it because you have fallen into quicksand? Well, don't worry. It just so happens that I know a lot about quicksand. So look and listen carefully. It will be very interesting and you might learn something.
>
> "First of all, Quicksand is not a special kind of sand. It is plain sand. But when water is forced upward through the sand, the grains are pushed apart and the sand swells. When this happens, the sand is no longer firm and cannot support heavy weight. That is why you are sinking. If the water stops or drains, the quicksand becomes plain sand again."
>
> "It's pulling me down!"

"No, that's not true. Quicksand does not pull you down. That's movie stuff. Instead, the weight of your body is making you sink. And if you struggle you will sink faster. So, stay calm.

"You see, when you struggle you push more quicksand out of the way and sink faster. I've noticed that most people, if they stay calm only sink up to their necks. If you had fallen on your back, you could have floated on top of it, the same way you can float on the Great Salt Lake or the Dead Sea. But it's a little late for that now." (pp. 1-10)

We see an example of an effect - cause ordering in David Macaulay's (1988) *The Way Things Work:*

My life as an inventor has not been without setbacks. Perhaps the most distressing was the failure of my athletic trophy business. Having perfected the folding rubber javelin and the stunning crystal discus, I entrusted their production to an apprentice. His initial enthusiasm however soon gave way to strange delusions of giant mammoths.

Assuming that he was simply overworked, I reduced his hours and improved ventilation in the workshop. But his condition deteriorated and one day he confronted me in my laboratory, claiming that miniature mammoths had invaded the premises. He insisted that a procession of these creatures was making its way across the wall, accompanied by a trail of smoke. Within the hour, word reached us that the workshop and all its contents had mysteriously burned to the ground. I realized that the frightened youth must have knocked over a candle as

> he fled, and although very disappointed at the loss, I decided to humor him and attribute the disaster to the spirits. (p. 190-191)

Later in the text we find out that the youth experienced the effects of bending and refracting light as it passed through the crystals he was working with. This accounted for the magnification of the mammoths walking outside his window as well as the tiny mammoths he saw marching along the wall. As the sun's rays passed through the window into the crystal discus, they were focused on the wall, forming a hot spot. This caused the trail of smoke the apprentice saw that eventually led to the workshop burning down.

In this example we are first presented the effects of light rays bending and refracting but as readers we do not know the causes of the mysterious events in the workshop (though some readers with prior exposure to the principles may hazard a guess) until we read on.

This study will focus on the effect of the causal structure presented in one of two ways: common (cause - effect) and inverted (effect - cause).

Reader. Norris et al.'s (2005) reader brings anticipation and expectations to the narrative. Although Schank and Berman (2002) and Graesser et al. (2002) do not include the reader in their narrative elements, this idea is found in their explanation of narrative impact. For example, Schank and Berman (2002) tell us that the story must engage the reader's interest, that the reader must want or need the information presented, that the reader needs to be able to relate to the story, and that the reader must be able to see themselves as the hero. Graesser et al. (2002) take this last idea further in his fusion facilitation hypothesis*,* saying that narrative should have the most impact when the hero is also the reader. Furthermore, the story written in second person should have a greater impact than one written in first person or third person, third person having the least impact. Graesser et al. (2002) hypothesize that this fusion of roles: narrator, hero and reader, will enhance memory.

Narrative appetite and past time. Norris et al. (2005) define two elements that are not included in the Schank and Berman (2002) or Graesser et al. (2002) models. These are narrative appetite (desire to know what will happen and creation of suspense (also in Green & Brock, 2002) through a wide variety of possibilities) and past time (narrative occurs in the past). Although these ideas are not included in the Schank and Berman (2002) and Graesser et al. (2002) theories, they are elements that are commonly seen in narratives.

Gender Differences in Science Comprehension and Retention

Gender differences in the comprehension and retention of scientific narrative will also be examined. Males tend to achieve better in science than females (Mau & Lynn, 2000) especially in physics (Johnson & Murphy, 1986 as cited in Tamir, 1988; Tamir, 1988) with the gender gap increasing through adolescence being smallest at age 10 and largest at age 17 (Johnson & Murphy, 1986 as cited in Tamir) . In addition, boys were found to be better able to apply physics concepts (Tamir, 1988) and performed better in inquiry-based physics courses (Cavallo et al. 2004).

Narrative elements may mediate these gender differences. A main character that the reader can relate to increases the narrative impact (Graesser et al. 2002, Schank & Berman, 2002). For example, Azencot & Blum (1985) found that males had a significantly higher affect score when reading a narrative with a male character. The concrete nature of the narratives may mediate the differences as well. Although a higher conceptual understanding of physics was associated with being male, it was also associated with higher levels of visualization ability (Damas, 1994).

Chapter 3: Method

Participants

The participants in the study were 94 high school students attending Pleasant Grove High School in Pleasant Grove, Utah. Participants were students enrolled in one of five physics courses: Two periods of Physics 1: Part 1 (11, 17), AP Physics (12), and two periods of Physics (25, 29). Of the original 116 students, 22 students either did not return the parental permission form or did not complete one or more assessments in the study.

Materials

The materials used in this study were a passage of scientific narrative in four forms, a pretest, a posttest and a concrete word test.

Texts. The participants read a passage of scientific narrative. It was hypothesized that concrete details and the causal structure would produce an instructional impact. To test the effects of these two elements, a base line of science narrative was constructed to hold constant all other narrative elements.

The base line science narrative used in this study consisted of the elements discussed in the last section, varying only the two independent variables: concrete details and causal structure (common vs. inverted). Norris et al.'s (2005) event-tokens ("something happened" (p. 4)) and past time were present in the narrative, as well as a spatial setting and context, explanation, a goal and an obstacle. The purpose of the text was to teach a science principle.

The narratives taught readers the basic principles of Einstein's Special Theory of Relativity. This theory was chosen because of the difficulty of the concepts and because few students have already studied the principles. Four versions of the narrative were constructed. The first consisted of abstract details and a common causal structure. The second consisted of concrete details and a common causal structure. The third consisted of abstract details and an inverted causal structure. The fourth consisted of concrete details and an inverted causal structure. Each narrative was based on the same story line: a student struggling to understand Einstein's Special Theory of Relativity and receiving instruction through a radio broadcast. The narratives featured two narrators cast as race announcers who provided the scientific explanation needed for the events as they unfold.

The stories were matched for number of ideas presented (7 ideas: 3 causal, 4 effect), readability (Grade levels 7.4 – 7.6 on the Flesch-Kincaid scale), and length (between 3105 - 3131 words). The common causal structure presented three causal ideas first: two postulates and an operational definition, followed by four effects. The inverted causal structure presented the four effects first followed by the three causal ideas. The abstract and concrete details varied in words, phrases or examples that were either more concrete or more abstract, depending on the type. For example, in Einstein's explanation (1961) of simultaneity, he refers to a person "M" and a person "F." The abstract version leaves these appellations unchanged but the concrete version names them "Marie" and "Fred" (see Appendix A for a more details on the differences in the forms).

Assessments. This section will review the comprehension and retention measures used in the published studies and discuss the measures that will be used in the present study. Because this is an area of research not much explored, few studies were available to inform this section. The studies discussed here are fairly close to the line of research as they compared narrative and expository text. However, these results should be viewed with caution as applied to this study because they did not control for the structure of the text.

Multiple-choice questions (Blake, 1985), true/false questions (Tun, 1989), interviews (Bonitatibus & Beal, 1996; Zabrucky & Moore, 1999), and inferential questions (Saenz & Fuchs, 2002) showed a comprehension effect for students reading a narrative text while explicit, implicit, contradictory and elaborated statements (Harris, Rogers & Qualis, 1998), and application and short answer questions (Alvermann, Hynd & Qian, 1995) showed a comprehension effect for students reading an expository text. Maria and Junge (1993) found no comprehension difference for text type when students took a short answer test and drew a diagram of the earth.

While it appears that comprehension effects depend on how they are measured, these results have questionable reliability because of the variation in the text structure. One does not know, for example, if the effect came because of the type of measure or because of the narrativity of the passage.

The same difficulty of comparing various text structures is found in the studies on retention. Retention favored narrative text when measured by analyzing an oral or written recall administered usually the same time as the reading (Lucas, 1981; Petros et al., 1989; Tun, 1989; Zabrucky & Moore, 1999; Zabrucky & Ratner, 1992). Hartley (1986), however, found that adults remembered expository material more easily than narrative material on a written recall test given a day later. Maria and Junge's (1993) study of fifth graders measured recall in three ways: Immediately after reading either a narrative or expository text on earth science, the students were asked to write what they remembered. One week later the students were given a short answer test and then asked to draw a diagram of the earth. Although they found a difference in recall between good and poor readers, no recall difference was found for text type.

For this study, information about the reader was collected in a pretest. Each reader completed four open-ended questions to assess the extent of their prior knowledge. In addition, each participant completed a short assessment adapted from the Intrinsic Motivation Inventory (IMI) (Deci & Ryan, 1985) to determine level of motivation in learning Einstein's Special Theory of Relativity. The IMI assesses a participants' subjective experience on seven subscales as related to learning about a target activity and has strong reliability and validity (Self-Determination, n.d.). The IMI was adapted for this study to assess the student's interest, pressure, effort, and value in relation to Einstein's Special Theory of relativity. Each of the four subscales consisted of four questions, totaling 16 questions. The scores for each of the four subscales: interest, pressure, effort, and value, and the knowledge pretest score were used as covariates for the study.

Both comprehension and retention were measured (Sadoski et al., 1993). Comprehension was measured on the posttest with multiple-choice problem-solving transfer questions (Mayer, 2002) and by the reader's ability to form an explanation of a physics concept (Schank, Kass & Riesbeck, 1994). Questions were adapted from a book by Russell Stannard (1989) on this topic and the chapter on the Theory of Special Relativity from the Physical Science 100 BYU Independent Study Course (Mason et al., 1989). The posttest was comprised of 15 questions of which 12 are multiple-choice questions and three are short answer questions. The explanation questions were similar to those found on the pretest. These questions were aligned with the physics concepts taught in the narrative.

Retention was tested by administering the transfer and explanation questions from the posttest again approximately one week later. The retention test included two additional questions to allow students to self-report outside study on the topic and/or whether they discussed or taught the concepts to someone else.

A concrete word test was also administered after the posttest. This instrument asked participants to rate words and phrases for their concreteness on a bipolar scale of one (very abstract, hard for me to form mental images of this) to seven (very concrete, easy for me to form mental images of this) (Sadoski et al., 1993).

Procedure

All students were given a parental permission form. Those students who returned the permission signed became participants in the study.

Research was conducted with all participants during their class times. Participants were given a randomly assigned packet from one of four groups. This packet, containing all materials, asked them to note their name, class ID number, date and gender. The teacher read the following instructions to each class:

> Thank you for participating. You will answer a few questions about yourself and what you already know about Einstein's Special Theory of Relativity, then you will read a story and answer the questions that follow. The packet is double-sided so be sure to look on both sides of each page. On the first page you will see four questions that ask what you already know about Einstein's theory. If you don't know the answers, that's OK. Just skip those questions and go on to the next part. DON'T GUESS. Read the story ONCE and please don't look back at the story

> once you start answering the questions. Again, thank you for participating and I hope you will find Einstein's theory worthwhile study.

Approximately one week after the first meeting, the participants again completed the posttest, noting their names, class ID number, date and gender on the test. The teacher read the following instructions to each class:

> This short test is to see what you remember from the story you read last week. There are questions on both sides of the page. Please answer them the best you can. Thank you for your help.

Research Design

Participants were randomly assigned to four experimental conditions in a 2 x 2 x 2 x 2 repeated measures ANCOVA design. The independent variables were the causal structure (common or inverted), and the detail type (abstract or concrete) and gender. The repeated measures variable was comprehension measured after the reading and again one week later. The following IMI variables: interest, pressure, value and effort as well as prior knowledge, tested by pretest, were measured as covariates for the study.

Partialing out the variance related to the reader covariates gives a clearer picture of what is happening with the independent variables. The ideal application for an ANCOVA is random assignment, where covariates are measured before the treatment (Howell, 2002). A factorial design was chosen to test the independent variables because the elegance of the factorial design enables the researcher to test the effect of each independent variable and any interaction between them.

Data Collection and Analysis

The researcher scored the pretest and the posttests using a key and a rubric. Another rater scored a random 14 posttests to determine reliability (Cronbach's alpha was .92). Explanations were scored by the overall correctness of informational ideas as determined in the rubric. Multiple-choice questions were scored with full points given for the correct answer, no points for an incorrect answer.

Pilot Studies

Pilot studies were conducted with all of the materials and measures to make certain that the study was properly planned.

A pre-pilot study was conducted with a concrete word test (Wharton, 1980) and an earlier version of both the pretest and the posttest. These three measures were tested by 50 participants, most of which were of college age. The pretest questions and the posttest were also sent to the physics faculty of BYU. While the faculty members were asked only to complete the assessment, most provided feedback on refining the assessment questions themselves. The concrete word test also provided important feedback. Wharton (1980) had just over 61 percent of his participants choose 74 percent of the concrete words (significant at the .01 level) with 16 percent choosing 93 percent of the concrete words (significant at the .0000001 level). In this pre-pilot, over 74 percent of the participants chose 74 percent or more of the concrete words, with 42 percent choosing over 93 percent of the concrete words. The concrete version appears to be more concrete when using Wharton's standards; nevertheless, the five concrete-version words that were chosen by less than 65% of the participants were replaced to improve the overall concreteness of the narrative. Overall, the responses from this pre-pilot study provided valuable feedback used to refine the materials as well as the pre- and post-test questions.

A pilot study was conducted on an evening section of Physics 106. The professor explained the study, telling students that it would teach them a topic that was difficult for many students to grasp. She then offered students 25 extra credit points on a homework assignment to participate in the study. Forty-three students participated the first evening completing the pretest, reading the narrative and completing the posttest as well as a concrete word test. One week later the retention test was administered with 35 of the original 43 students participating.

Several of the students commented on the study as they were leaving. Comments included “fun,” “interesting,” “very clever,” “very well written,” “that was actually almost enjoyable,” “this candy will weigh more as it’s moving with me,” “that was so good.” A couple of students made suggestions on how to improve the study: Mix up the concrete and abstract words on the concrete word test so that the abstract and concrete word comparisons are not together, and change the professor from a male to a female. One student commented that she was going to tell her roommates about the tortilla gaining mass and another student asked for a copy of the story to share with a roommate. The students took between 20-50 minutes to complete the first part of the study. The retention test took students between 5-15 minutes to complete.

Results of the pilot prompted several changes to the assessments and story. Question 7 was not discussed directly in the story and did not relate directly to Special Relativity so was therefore discarded. A number of students had difficulty answering the question about time stopping as one rides away on a light beam. The question was improved to eliminate any confusion. A couple of students asked about the application question on length contraction prompting more explanation in the narrative. Several questions were eliminated to even out the number of application questions for each concept. An additional question was added to test their understanding of frames of reference.

The concrete word test revealed that the mean for the abstract words and phrases was 5.078 while the mean for the concrete words and phrases was 5.60. An independent editor reviewed the narratives and made suggestions to make the abstract narrative more abstract and the concrete narrative more concrete. The editor first read the abstract narrative and then the concrete narrative. She commented that the concrete was much easier to understand. The results of the concrete test were also used to prompt changes to the narratives. Abstract words and phrases that scored an average of 5.0 or above were changed. Concrete words and phrases that scored an average below 5.0 were changed to be more concrete. The concrete word test reflected these changes.

Additionally, administrative changes were made for the study. Instructions to read the story only once were included before the reading passage. Instructions were also added at the beginning of the posttest indicating that students should not go back to find answers to the questions. Students were advised that they should not guess during the pretest.

The scores were entered into a 2 (Concreteness) x 2 (Causal Structure) MANCOVA. There were no main effects for concreteness or causal structure on comprehension or retention. However, there was a significant Concreteness x Causal Structure interaction [$F(1, 34) = 4.322$, $p < .05$)] on comprehension. The results shown in

Table 2, even with small sample sizes, suggested that there could be some significant findings in the study.

A second study was conducted with a daytime section of Physics 106. It was expected that this would be the final study. With a promise of extra credit from the teacher, the students were given the last 20 minutes of class to complete the packet. One hundred and six students remained in class to participate. However, at the end of class time, many students had to leave for other classes and the next class began to enter the classroom creating noise and confusion. When the next class began, a few of the students moved into the hallway outside the classroom to finish the study. Almost all students finished the posttest and 76 students finished the concrete word test. A week later, students took the retention test to which was added a question: “Did you have enough time to finish reading the story last Friday? YES NO” Only 49 students answered positively. Participants who indicated that they did not have time to finish reading the story were not included in the study. With only 49 students participating, this study became a second pilot.

This pilot prompted changes to the pretest. There were a few comments made that the IMI was overly redundant. In response, the scale was shortened to include only four questions from each subscale. The instructions indicating the participants shouldn't guess on the pretest were also bolded. The stories were changed to better match high school students' experience (e.g. a male teacher instead of a female professor, a physics class during a term instead of Introduction to Physics class during a semester). Perhaps because of the time limitations and pressure to complete the study that participants in this pilot experienced, there were no significant main effects or interactions (Table 3).

Table 2

Tests of Between-Subjects Effects for Pilot 1

Source	Dependent Variable	*df*	*F*	*p*
Pretest	Comprehension	1	3.50	.07
	Retention	1	1.25	.27
Interest	Comprehension	1	1.10	.30
	Retention	1	1.50	.23
Pressure	Comprehension	1	1.24	.27
	Retention	1	8.99	.01*
Value	Comprehension	1	5.57	.03*
	Retention	1	0.53	.47
Effort	Comprehension	1	1.11	.30
	Retention	1	0.51	.48
Causal Structure (A)	Comprehension	1	2.56	.12
	Retention	1	1.07	.31
Concrete (B)	Comprehension	1	1.56	.22
	Retention	1	0.02	.90
A x B	Comprehension	1	4.32	.05*
	Retention	1	0.11	.74
Error	Comprehension	26		
	Retention	26		

*$p \leq .05$

Table 3

Tests of Between-Subjects Effects for Pilot 2

Source	Dependent Variable	*df*	*F*	*p*
Interest	Retention	1	0.00	0.99
	Comprehension	1	3.15	0.08
Pretest	Retention	1	0.75	0.39
	Comprehension	1	0.63	0.43
Effort	Retention	1	1.00	0.32
	Comprehension	1	0.00	0.97
Value	Retention	1	2.01	0.16
	Comprehension	1	0.90	0.35
Pressure	Retention	1	0.23	0.63
	Comprehension	1	0.90	0.35
Causal Structure (A)	Retention	1	0.32	0.57
	Comprehension	1	0.78	0.38
Concreteness (B)	Retention	1	0.02	0.89
	Comprehension	1	0.00	0.97
A x B	Retention	1	0.43	0.51
	Comprehension	1	0.03	0.85
Error	Retention	36		
	Comprehension	36		

Chapter 4: Results

The scores were entered into a 2 (Concreteness) x 2 (Causal Structure) x 2 (Gender) x 2 (Comprehension as the within-subjects factor) ANCOVA (B. Tabachnick, email correspondence, July 2008) with effort as covariate, alpha level set at $p = .05$. Five missing values in the IMI were replaced with the subscore mean (E. Deci, email correspondence, May 2008).

ANCOVA Assumption Tests

The statistical assumptions of repeated measures ANCOVA were tested including normality of variables, linearity of regression, homogeneity of variance (Levene's Test of Equality of Error Variances (Comprehension $F(7, 86) = 1.004$, $p > .05$, Retention $F(7, 86) = .950$, $p > .05$)), sphericity (Bartlett's Test of Sphericity $p < .05$), and homogeneity of regression (Concrete x Effort $F(2, 85) = 1.188$, $p > .05$, Causal Structure x Effort $F(2, 85) = 4.24$, $p > .05$, Gender x Effort $F(2, 85) = 4.24$, $p > .05$). Box's Test of Equality of Covariance Matrices (Box's M) was used and showed significance [$F(21, 13876) = 1.634$, $p < .05$]. However, because the cell sample sizes were unequal (see Table 5 for standard deviations and sample sizes) and Box's M is thought to be a sensitive test, Tabachnick and Fidell (2007, p. 252) recommend testing Box's M at the $p = .001$ level. The data passes the equality of covariance matrices test with the recommended revised significance level.

The results of these tests indicated that repeated measures ANCOVA was an appropriate procedure for this data set.

Preliminary Analysis of Covariates

Tabachnick and Fidell (2007, p. 212) recommend a preliminary analysis of covariates to choose the best set (i.e. the smallest number of covariates (Huck, 2000) that are uncorrelated with each other but correlated to the dependent variable) for the study. They suggest using stepwise regression or correlation statistics as the means to choose the most representative of a group when previous studies are unavailable to inform covariate selection. Correlations of the covariates and dependent variables were analyzed using Spearman's rho (Table 4). The IMI covariates (pressure, value, effort, interest) were found to be significantly correlated to each other and the within-subjects variable comprehension. The covariate effort had a slightly higher R^2 at .137 than interest (R^2 = .111) and showed significance in the multivariate tests when all five covariates were included, where interest did not. To increase the power of the ANCOVA, the covariates pressure, value, and interest were dropped from the analysis (Huck, 2000; Tabachnick & Fidell, 2007). The pretest covariate was not normally distributed and showed very little correlation to the dependent variables and was therefore also dropped from the analysis. Effort was chosen as the representative covariate. Effort reduced the error term for comprehension (*df* = 85, Sum of Squares difference = 430).

ANCOVA Results

Sample size among the eight groups varied between seven and sixteen participants. The means, standard deviations and sample sizes for each of the groups are shown in Table 5. Scores for comprehension were on a scale from 0 to 30 points.

Table 4

Spearman Correlations for Covariate and Dependent Measures

	Pretest	Interest	Pressure	Value	Effort	Test 1	Test 2
Pretest		.099	.007	.105	.097	-.002	.008
Interest			-.423**	.639**	.763**	.377**	.377**
Pressure				-.220*	-.274**	-.228*	-.319**
Value					.656**	.350**	.238**
Effort						.395**	.339**
Test 1							.767**

*Correlation is significant at the .05 level (2-tailed).
**Correlation is significant at the .01 level (2-tailed).

Table 5

Means and Standard Deviations of the Comprehension and Retention Tests

	Causal Structure	Concreteness	Gender	*M*	*SD*	*n*
Test 1	Inverted	Concrete	Female	24.96	3.80	12
			Male	25.22	4.20	16
		Abstract	Female	21.30	6.41	10
			Male	20.32	5.46	11
	Common	Concrete	Female	20.93	5.62	7
			Male	22.88	5.79	13
		Abstract	Female	17.60	6.75	10
			Male	25.00	5.45	15
Test 2	Inverted	Concrete	Female	25.13	3.40	12
			Male	25.72	3.71	16
		Abstract	Female	18.00	7.38	10
			Male	17.45	8.44	11
	Common	Concrete	Female	24.07	5.91	7
			Male	20.65	7.19	13
		Abstract	Female	15.80	6.66	10
			Male	23.73	5.94	15

The effect size measure for this study is partial η^2, which is appropriate for multivariate designs (Tabachnick & Fidell, 2007). Effect size measures the strength of association between the dependent variable and the independent variable. According to Pallant (2007, p. 208), Cohen's (1988) guidelines η^2 for interpreting effect sizes can be used to interpret partial η^2 as well. She refers the reader to Tabachnick and Fidell (2007, p. 55) for their guidelines for interpreting partial η^2 which are small ($\eta^2 = .01$), medium ($\eta^2 = .09$), large ($\eta^2 = .25$). Effect size confidence intervals were computed with Smithson's (2003) SPSS scripts.

Multivariate tests (Table 6) showed significance for Comprehension x Concreteness [F (1, 85) = 9.92, $p < .01$, $\eta^2 = .10$ with confidence limits between .02 and .21].

Table 6

Multivariate Tests

Effect	Pillai's Trace Value	*F*	Hypothesis *df*	Error *df*	*P*	Partial η^2	CI around Partial η^2 for α *lower*	*upper*
Comprehension (A)	0.00	0.20	1	85	0.65	0.00	.00	.05
Comprehension x Effort	0.00	0.04	1	85	0.85	0.00	0.00	0.02
A x Gender (B)	0.02	1.39	1	85	0.24	0.02	0.00	0.08
A x Causal Structure (C)	0.01	0.98	1	85	0.33	0.01	0.00	0.07
A x Concreteness (D)	0.10	9.92	1	85	0.00**	0.10	0.02	0.21
A x B x C	0.03	2.66	1	85	0.11	0.03	0.00	0.11
A x C x D	0.01	0.71	1	85	0.40	0.01	0.00	0.07
A x B x D	0.04	3.09	1	85	0.08	0.04	0.00	0.12
A x B x C x D	0.03	2.86	1	85	0.09	0.03	0.00	0.11

$^*p < .05$, $^{**}p < .01$

The Tests of Between–Subject Effects (Table 7) revealed a significant effect for effort [F (1, 85) = 16.59, $p < .01$]. Concreteness showed significance [F (1, 85) = 11.97, $p < .01$; $\eta^2 = .12$ with confidence limits between .03 and .23]. There was a significant interaction for Gender x Causal Structure x Concreteness [F (1, 85) = 5.01, $p < .05$, η^2 = .06 with confidence limits between 0 and .15].

Table 7

Tests of Between-Subjects Effects

Source	*df*	*F*	*p*	Partial η^2	CL around Partial η^2 for α	
					lower	*upper*
Effort	1	16.59	0.00**	0.16	0.06	0.28
Gender (A)	1	2.06	0.15	0.02	0.00	0.10
Causal Structure (B)	1	3.25	0.08	0.04	0.00	0.12
Concreteness (C)	1	11.97	0.00**	0.12	0.03	0.23
A x B	1	2.89	0.09	0.03	0.00	0.11
A x C	1	1.88	0.17	0.02	0.00	0.09
B x C	1	2.85	0.10	0.03	0.00	0.11
A x B x C	1	5.01	0.03*	0.06	0.00	0.15
Error	85					

*$p < .05$, **$p < .01$

Adjusted means for each of the main effects and interactions are shown in Table 8. Means for Concreteness, Comprehension, Concreteness x Comprehension, and Gender x Causal Structure x Concreteness showed significance.

The interactions of Concreteness x Comprehension were graphed in Figure 1 and Gender x Causal Structure x Concreteness interactions were graphed in Figure 2.

Table 8

Adjusted Means from Analysis of Covariance for Effort

				M	*SE*	*p*
Gender (A)			Female	21.04	0.82	
			Male	22.57	0.68	.15
Causal Structure (B)			Inverted	22.79	0.74	
			Common	20.82	0.79	.08
Concreteness (C)			Concrete	23.64	0.76	
			Abstract	19.97	0.75	.00**
Comprehension (D)			Test 1	22.28	0.53	
			Test 2	21.33	0.61	.03*
A x B		Female	Inverted	22.93	1.08	
			Common	19.15	1.24	
		Male	Inverted	22.65	0.99	
			Common	22.49	0.96	.09
A x C		Female	Concrete	23.61	1.19	
			Abstract	18.47	1.12	
		Male	Concrete	23.68	0.93	
			Abstract	21.46	0.99	.17
A x D		Female	Test 1	21.27	0.81	
			Test 2	20.82	0.95	
		Male	Test 1	23.30	0.67	
			Test 2	21.84	0.79	.24
B x C		Inverted	Concrete	25.53	0.96	
			Abstract	20.05	1.11	
		Common	Concrete	21.76	1.17	
			Abstract	19.88	1.03	.10
B x D		Inverted	Test 1	23.49	0.73	
			Test 2	22.09	0.85	
		Common	Test 1	21.08	0.78	
			Test 2	20.56	0.91	.33
C x D		Concrete	Test 1	23.45	0.75	
			Test 2	23.84	0.88	
		Abstract	Test 1	21.12	0.74	
			Test 2	18.81	0.87	.00**
A x B x C	Female	Inverted	Concrete	25.21	1.44	
			Abstract	20.65	1.60	
		Common	Concrete	22.01	1.89	
			Abstract	16.30	1.58	
	Male	Inverted	Concrete	25.85	1.25	
			Abstract	19.45	1.51	
		Common	Concrete	21.51	1.39	
			Abstract	23.47	1.31	.03*

Table 8 (continued)

Adjusted Means from Analysis of Covariance for Effort

					M	*SE*	*P*
A x B x D		Female	Inverted	Test 1	23.72	1.07	
				Test 2	22.14	1.25	
			Common	Test 1	18.81	1.22	
				Test 2	19.50	1.43	
		Male	Inverted	Test 1	23.25	0.97	
				Test 2	22.05	1.14	
			Common	Test 1	23.35	0.95	
				Test 2	21.62	1.11	.11
A x C x D		Female	Concrete	Test 1	22.78	1.18	
				Test 2	24.44	1.38	
			Abstract	Test 1	19.75	1.10	
				Test 2	17.19	1.30	
		Male	Concrete	Test 1	24.11	0.92	
				Test 2	23.24	1.08	
			Abstract	Test 1	22.49	0.98	
				Test 2	20.43	1.15	.08
B x C x D		Inverted	Concrete	Test 1	25.37	0.95	
				Test 2	25.69	1.11	
			Abstract	Test 1	21.61	1.10	
				Test 2	18.50	1.29	
		Common	Concrete	Test 1	21.52	1.16	
				Test 2	21.99	1.36	
			Abstract	Test 1	20.64	1.02	
				Test 2	19.13	1.20	.40
A x B x C x D	Female	Inverted	Concrete	Test 1	25.13	1.43	
				Test 2	25.29	1.68	
			Abstract	Test 1	22.32	1.58	
				Test 2	18.98	1.86	
		Common	Concrete	Test 1	20.43	1.87	
				Test 2	23.59	2.20	
			Abstract	Test 1	17.19	1.57	
				Test 2	15.04	1.84	
	Male	Inverted	Concrete	Test 1	25.61	1.24	
				Test 2	26.09	1.45	
			Abstract	Test 1	20.89	1.50	
				Test 2	18.01	1.76	
		Common	Concrete	Test 1	22.62	1.37	
				Test 2	20.39	1.61	
			Abstract	Test 1	24.08	1.30	
				Test 2	22.85	1.52	.09

$^{*}p < .05$, $^{**}p < .01$

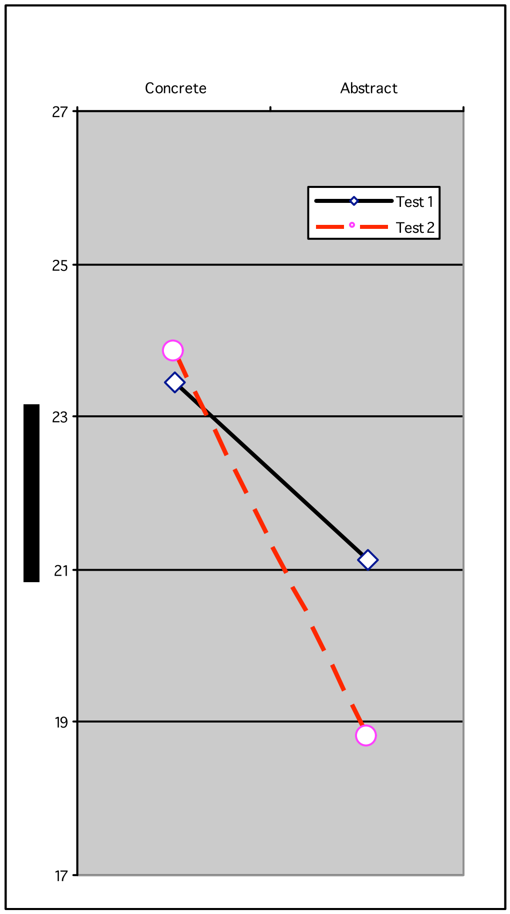

Figure 1. Two-way Interaction of Degree of Concreteness by Comprehension

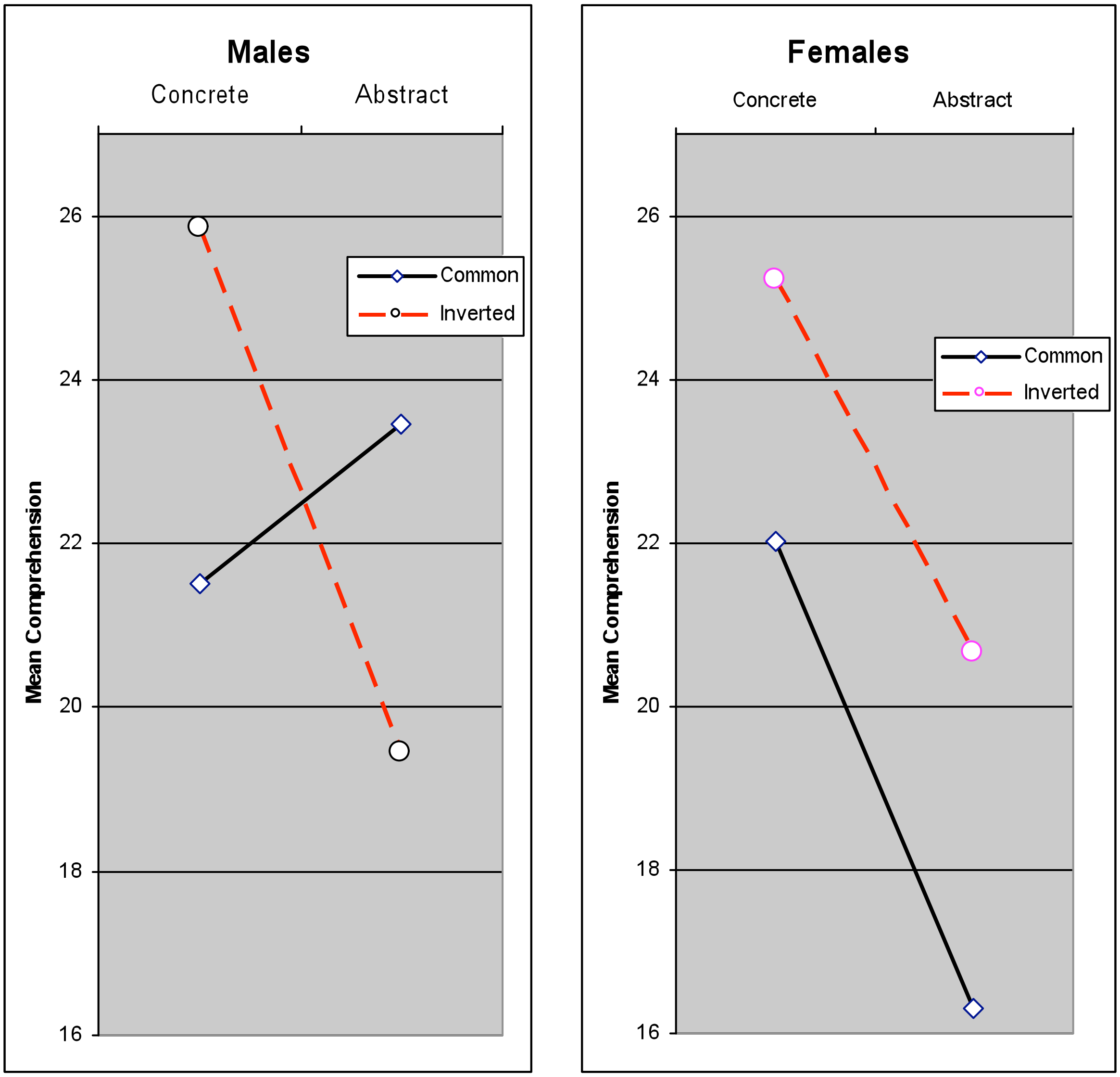

Figure 2. Three-way Interaction of Degree of Concreteness by Causal Structure by Gender

Five students responded on the retention test that they had explained or discussed concepts from Einstein's Special Theory of Relativity since reading the story. One said that she asked someone if they knew about the theory and another said she told someone it was confusing. No student reported having read or studied anything further about the theory.

The concrete word test revealed an abstract score (N = 94, $M = 4.90$) and a concrete score (N = 95, $M = 5.44$).

Chapter 5: Discussion

This section will present a brief summary of the findings for each of the hypotheses. It will also discuss the limitations of the study and recommend possible avenues for further research.

The Effect of the Study Variables on Comprehension

The goal of this study was to discover the possible impacts of two narrative elements (concreteness and causal structure) and gender on comprehension. Overall, concreteness had an impact on comprehension. Gender, comprehension and causal structure combined had an impact on comprehension.

Concreteness. As hypothesized, the concrete narrative seemed to be more easily understood than the abstract version (means 23.64 and 19.97). The effect on comprehension agrees with results that some have found using concrete words and phrases to teach other subjects (Graves et al., 1991; Sadoski et al., 2000; Wharton, 1980). There was a question as to how much concreteness could effect instruction of the abstract principles often found in science instruction (Sadoski et al., 2000). Einstein's Special Theory of Relativity, in particular, is difficult conceptually and requires higher-order thinking (Stannard, 2001). The effect of concreteness for physics instruction may lie in its ability to provoke imagery which can improve comprehension through effective encoding of the information (Driscoll, 2000; Clark & Paivio, 1991). In a study of college age students in an introduction to physics class (Damas, 1994), higher conceptual understanding of physics was associated with the student's ability to visualize.

The concrete version on the narrative was also more easily remembered. Concrete means for Test 1 (23.45) and Test 2 (23.84) showed a slight gain in retention while abstract means Test 1 (21.12) and Test 2 (18.81) showed a small loss in retention (see Fig. 1). This follows the idea that details that provoke images are more easily recalled (Chambliss, 2002) and that they can serve as a prompt for an entire story at a later time (Green & Brock, 2002). This improved recall effect was also seen when teaching other subjects with concreteness (Hidi & Baird, 1988; Sadoski et al., 1993).

Not only did the concrete version of the narrative make the concepts more easily remembered, but it seemed to have the interesting effect of *improving* the score of the recall test for females (means concrete Test 1: 22.78, Test 2: 24.44, abstract Test 1: 19.75, Test 2: 17.19) but not for males (means concrete Test 1: 24.11, Test 2: 23.24, abstract Test 1: 22.49, Test 2: 20.43). In searching for an explanation for the gender difference, the participant's scores on the concrete word test were analyzed but only a small difference was found in the means (female: 5.27, males: 5.12). This gender difference may partially be a result of relating to the main character in the story (Schank & Berman, 2002).

Causal structure. The order the concepts were presented in the story did not make a statistically significant difference in the comprehension of the participants. Contrary to the hypothesis, narratives that used the inverted order (effect-cause) were comprehended better than those that used the common order (cause-effect) (means inverted 22.79, common 20.82, p = .08). This is an interesting result given that novice practitioners build cause-effect mental models (Leon & Penalba, 2002) and that the presentation of information in an effect-cause order is said to increase the processing time and difficulty of the text (Chambliss, 2002; Leon & Penalba, 2002). Standard (2001), in contrast, promotes teaching the difficult concepts of Einstein's Special Theory of Relativity using an effect-cause order because the effects are more concrete and the cause is more abstract. This order, he says, allows the student who has not yet reached formal operations to comprehend the information more easily.

Causal structure had little effect on retention for the participants (adjusted means inverted Test 1: 23.49, Test 2: 22.09; common Test 1: 21.08, Test 2: 20.56).

Causal structure seemed to have the most impact on females (adjusted means inverted 22.93, common 19.15) than males (adjusted means inverted 22.65, common 22.49).

The Causal Structure — Concreteness interaction on comprehension was not significant as predicted by the hypothesis (adjusted means inverted concrete: 25.53, abstract 20.05; common concrete: 21.76, abstract 19.88).

Gender. An effort was made to equalize the two genders in comprehension and retention by making the main character of the story female (enhancing the narrative impact through relating to the hero (Schank & Berman, 2002)). The differences in comprehension and retention were not statistically significant but there were interesting gender differences in the results.

Overall, males had slightly higher comprehension means than females (22.57, 21.04; $p = .15$). The most interesting gender differences were mentioned in the previous two sections of the discussion. Females reading the concrete version of the narrative generally improved their score from the test given a week earlier, scoring higher on the retention test (Test 1: 22.78, Test 2: 24.44) instead of lower as did the other four groups.

The Gender x Causal Structure x Concreteness interactions for comprehension (Fig. 2) further illustrate the gender differences. Male participants reading the inverted, concrete version and the abstract, common version scored higher than the other two groups showing a preference for "all concrete" or "all abstract" in both order of presentation and language. Whereas, female participants scored higher in the concrete versions and in the inverted versions showing a preference for concreteness.

Practical Significance of the Results.

Looking at the effect sizes and the adjusted means in the study assists us in determining the practical significance of the effects of concreteness and causal structure.

The effect size for concreteness was moderate ($\eta^2 = .12$ with confidence limits between .03 and .23). The adjusted means were 23.64 for concrete and 19.97 for abstract, a difference of almost four points on a 30 point scale. The effect size was also moderate for concreteness by comprehension ($\eta^2 = .10$ with confidence limits between .02 and .21). The adjusted means showed a slight gain for concrete (Test 1: 23.45, Test 2: 23.84) and a loss for abstract (Test 1: 21.12, Test 2: 18.81), a difference of a little over two points on a 30 point scale. The small gain in the concrete version, however, indicated no loss in the retention of concepts on average. Given that the concrete word test scores were not as different as anticipated (abstract = 4.90, concrete = 5.44 on a 7 point scale), it would appear that even relatively small changes to the concreteness of the narrative could have an effect on comprehension and retention.

The effect size for causal structure was small ($\eta^2 = .04$ with confidence limits between 0 and .12). The adjusted means for inverted (22.79) and common (20.82) showed an almost two point gain on a 30 point scale. The effect size of causal structure by comprehension was also small ($\eta^2 = .03$ with confidence limits between 0 and .07).

The adjusted means for inverted (Test 1: 23.49, Test 2: 22.09) and for common ordering (Test1: 21.08, Test 2: 20.56), showed less than a two point difference on a 30 point scale.

The effect size for gender was small ($\eta^2 = .02$ with confidence limits between 0 and .10). The adjusted means for males (22.57) and females (21.04) showed a less than two point difference on a 30 point scale. The effect size of gender by comprehension was small as well ($\eta^2 = .02$ with confidence limits between 0 and .08). The adjusted means for males (Test 1: 23.30, Test 2: 21.84) and females (Test 1: 21.27, Test 2: 20.82) showed a less than two point difference on a 30 point scale.

All other non-statistically significant interactions had small effect sizes ($.01 \leq \eta^2 \leq .04$) (see Table 6 and Table 7 for effect sizes and confidence limits and Table 8 for adjusted means).

Limitations of the Study

There were several limitations in the present study. First the sample size (N = 94) was small for a 2 x 2 x 2 x 2 repeated measures ANCOVA. The group sizes were not only small but unequal, ranging from 7 to16 participants.

Another limitation of the study was the researcher's limited writing skills. As the materials were developed for the study by the researcher, it is quite possible that a more refined version of the narrative could be conceived and written that would teach the subject more effectively and with greater difference between the concrete and abstract versions.

Conducting a qualitative interview after the retention test would have allowed the researcher to ask the participants more particularly what they understood from the narrative as well as how they felt they learned from the narrative. To better gauge the instructional impact, participants could also have been asked how engaging the story was and how they related to the story and the main character (Schank & Berman, 2002).

Testing the retention at longer intervals would have revealed more about the narrative elements effects on recall. Participants could have been tested at one week, one month, and three months.

Implications and Recommendations

In spite of the limitations mentioned above, this study has provided a first few steps in discovering narrative effect in science instruction. It outlined the narrative elements and provided research on two of the narrative elements while controlling for passage content, difficulty, and other narrative elements.

Overall, it would seem that learning even difficult concepts in physics through narrative is possible and effective. In the present study, 60 students scored zero points on the pretest with only two students scoring the full six points. Over seventy percent of students scored 20 points or higher (out of 30) on the comprehension test with over twenty percent scoring 28 or 30 points.

In this study, the results support the conclusion that the narrative element – concrete details – can have an instructional impact on comprehension and retention.

There are several recommendations for further study. This research was prompted by a question by Norris et al. (2005) that asked, “What features of narrative prove through empirical research to be most crucial, and how do they operate? Are there degrees of narrativity associated with degrees of narrative effectiveness?” (p. 25). The present study began a partial answer to the first part of the first question, namely, “What features of narrative prove through empirical research to be most crucial?” Much more remains to be examined in just this question. Such as, how do the other narrative elements impact comprehension and retention? How do the elements work in concert with each other? What are the interaction effects among the narrative elements? Norris et al.'s (2005) further questions are how the elements operate and if there are degrees of narrativity associated with degrees of narrative effectiveness.

The gender differences found in this study were also of interest. Does each narrative element have a different impact depending on the gender of the reader? Are some narrative elements more important to one gender and less so to another as related to their comprehension and retention?

It is hoped that the present study will provide researchers with a springboard for further research into the narrative effect. It is also hoped that it will provide instructional designers and physics teachers with information and ideas to improve the presentation of physics instruction.

References

Abbott, H. P. (2002). The Cambridge introduction to narrative. Cambridge, England: Cambridge University Press.

Alvermann, D. E., Hynd, C. E., & Qian, G. (1995). Effects of interactive discussion and text type on learning counterintuitive science concepts. *The Journal of Educational Research, 88*, 146-154.

Azencot, M. & Blum, A. (1985). Effects of a story-based strategy to enhance pupils' ability and motivation to read bio-technical texts. *Journal of Biological Education, 19,* 63-66.

Blake, M. E. (1985). The relationship between field dependence-independence and the comprehension of expository and literary text types. *Reading World, 24*(4), 53-62.

Bonitatibus, G. J., & Beal, C. R. (1996). Finding new meanings: Children's recognition of interpretive ambiguity in text. *Journal of Experimental Child Psychology, 62*, 131-150.

Bruner, J. (2002) *Making stories*. New York: Farrar, Strauss, and Giroux.

Campbell, P. (1998). Using stories to enrich the physics curriculum. *Physics Education, 33*, 356-359.

Cavallo, A. M. L.; Potter, W. H. & Rozman, M. (2004). Gender Differences in Learning Constructs, Shifts in Learning Constructs, and Their Relationship to Course Achievement in a Structured Inquiry, Yearlong College Physics Course for Life Science Majors. *School Science and Mathematics, 104,* 288-300.

Chambliss, M. J. (2002). The characteristics of well-designed science textbooks. In J. Otero, J.A. Leon, & A. C. Graesser (Eds.), *The Psychology of Science Text Comprehension* (pp. 51-72). Mahwah, NJ: Erlbaum.

Clark, J. M. & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3*, 149-210.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Cook, G. R. (2000). *Teaching by the Spirit.* Salt Lake City: Deseret Book Company.

Cooper, C. (2001). *Physics matters! Vol. 10 Nuclear physics*. Danbury, CT: Grolier Educational

Damas, G. (1994). *Factors influencing conceptual understanding in introductory college physics courses.* Unpublished doctoral dissertation. University of Miami.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York: Plenum Publishing Co.

DePaola, T. (1977). *The quicksand book*. New York: Holiday House.

DiPardo, A. (1989). Narrative knowers, expository knowledge: Discourse as a dialectic. Retrieved Oct 4, 2005, from http://www.writingproject.org/downloads/csw/OP06.pdf

Edelson, D. C. (1993). *Learning from stories: Indexing and reminding in a socratic case-based teaching system for elementary school biology*. Unpublished doctoral dissertation, Northwestern University.

Einstein, A. (1961). *Relativity: The Special and the General Theory; a popular exposition.* New York: Crown Publishers.

Engel, S. (1999). *Context is everything: The nature of memory,* W.H. Freeman & Co.

Estes, T. H., & Vasquez-Levy, D. (2001). Literature as a source of information and values. *Phi Delta Kappan, 82*, 507.

Folino, D. A. (2001). Stories and anecdotes in the chemistry classroom. *Journal of Chemical Education, 78*, 1615-1618.

Furlong, N., Lovelace, E. & Lovelace, K. (2000). *Research methods and Statistics: An Integrated approach.* Orlando, FL: Harcourt Brace & Company

Gamow, G. (1965). *Mr Tompkins in paperback*, Cambridge University Press.

Gamow, G. & Stannard, R. (1999). *The new world of Mr. Tompkins*, Cambridge University Press.

Goldman, S. R. & Bisanz, G. L. (2002). Toward a functional analysis of scientific genres: Implications for understanding and learning processes. In J. Otero, J.A. Leon, & A. C. Graesser (Eds.), *The Psychology of Science Text Comprehension* (pp. 19-50). Mahwah, NJ: Erlbaum.

Graesser, A., Leon, J. & Otero, J. (2002). Introduction to the psychology of science text comprehension. In J. Otero, J.A. Leon, & A. C. Graesser (Eds.), *The psychology of science text comprehension* (pp. 1-15). Mahwah, NJ: Erlbaum.

Graesser, A., McNamara, D. & Louwerse, M. (2002) What do students need to learn in order to process coherence relations in narrative and expository Text? Retrieved October 3, 2005 from: http://internal.autotutor.org/papers/artspdfs/Rethinking%20reading%20comprehension.pdf.

Graesser, A., Olde, B., Klettke, B. (2002). How does the mind construct and represent stories? In M. Green, J. Strange, & T. Brock (Eds.), *Narrative impact* (pp. 229-262). New Jersey: Lawrence Erlbaum Associates, Inc.

Graves, M. F., Prenn, M. C., Earle J., Thompson, M., Johnson, V., & Slater, W.H. (1991). Improving instructional text: Some lessons learned. *Reading Research Quarterly, 26*, 110-122.

Harris, J. L., Rogers, W. A., & Qualls, C. D. (1998). Written language comprehension in younger and older adults. *Journal of Speech, Language and Hearing Research, 41*, 603-617.

Hartley, J. T. (1986). Reader and text variables as determinants of discourse memory in adulthood. *Psychology and Aging, 1*, 150-158.

Hendrickson, L. (1999) Lessons from Linnea: *Linnea in Monet's Garden* as a prototype of radical change in informational books for children. *Children's Literature in Education, 30*, 35-45

Hernandez-Serrano, J. (2001) *Effects, meaning and learning processes regarding experts' stories and novice problem solving in an iIllstructured problem-solving environment*. Unpublished doctoral dissertation, Pennsylvania State University.

Hernandez-Serrano, J., Stefanou, S.E., Hood, L.F., & Zoumas, B.L. (2002). Using experts' experiences through stories in teaching new product development. *Journal of Product Innovation Management, 19*, 54.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics, 55* , 440-454.

Hidi, S. & Baird, W.H. (1988). Strategies for increasing text-based interest and student's recall of expository texts. *Reading Research Quarterly, 23*, 465-483.

Holzner, S. (2006). *Physics for dummies*. Hoboken, NJ: Wiley Publishing Company, Inc.

Howell, D. C. (2002). *Statistical methods for psychology*. Duxbury: Thompson Learning.

Huck, S. W. (2000). *Reading statistics and research*. New York: Addison-Wesley Longman, Inc.

Kalchman, M. (1998). Storytelling and astronomy. *Science and Children, 36*(3), 28-31.

Krauss, L. M. (1993). *Fear of physics: A guide for the perplexed*. New York, NY: BasicBooks.

Leal, D.J. (1993). Storybooks, information books and informational storybooks: an explication of the ambiguous grey genre. *The New Advocate, 6,* 61-70.

Leal, D. (1994). A comparison of third grade children's listening comprehension of scientific information using an information book and an informational storybook. In C.K Kinzer & D.J. Leu (Eds.), *Mulitdimensional aspects of literacy research, theory, and practice. Forty-third Yearbook of The National Reading Conference* (pp. 137-145). Chicago, IL: The National Reading Conference.

Leon, J. A. & Penalba, G. E. (2002). Understanding causality and temporal sequence in scientific discourse. In J. Otero, J.A. Leon, & A. C. Graesser (Eds.), *The psychology of science text comprehension* (pp. 155-178). Mahwah, NJ: Erlbaum.

Lin, L. M., Moore, D., & Zabrucky, K. M. (2000). Metacomprehension knowledge and comprehension of expository and narrative texts among younger and older adults. *Educational Gerontology, 26*, 737-749.

Lucas, D. (1981). *Effects of discourse type on recall of children and adults*. Unpublished doctoral dissertation, Cornell University, Ithaca, NY.

Macaulay, D. (1988). *The way things work*. Boston: Houghton Mifflin Company.

Maria, K. & Junge, K. (1993, December). *A comparison of fifth graders' comprehension and retention of scientific information using a science textbook and an informational storybook*. Paper presented at the Annual Meeting of the National Reading Conference, Charleston, SC.

Martin, B. E. and Brouwer, W. (1991). The sharing of personal science and the narrative element in science education. *Science Education, 75,* 707-722.

Martin, K. and Miller, E. (1988) Storytelling and science. *Language Arts, 65*, 255-259

Mason, G. W., Griffen, D. T., Merrill, J. J., & Thorne, J. M. (1989). *Physical science concepts*. Provo, Utah: Brigham Young University.

Mattingly, C. (1991). Narrative reflections on practical actions: Two learning experiments in reflective storytelling. In D. A. Schon (Ed.), The reflective turn: Case studies in and on educational practice (pp. 235-257). New York: Teachers College Press.

Mau, W.- C. and Lynn, R (2000). Gender differences in homework and test scores in Mathematics, Reading and Science at tenth and twelfth grade. *Sexualities, Evolution & Gender,* 2, 119 – 125.

Mayer, R. E. (2002). Using illustrations to promote constructivist learning from science text. In J. Otero, J.A. Leon, & A. C. Graesser (Eds.), *The psychology of science text comprehension* (pp. 333-356). Mahwah, NJ: Erlbaum.

Neufeldt, V. & Guralink, D. B. (Eds.). (1991). Webster's new world dictionary of American English. (3rd ed.). New York: Prentice Hall.

Norris, S., Guilbert, S., Smith, M., Hakimelahi, S., & Phillips, L. (2005). A theoretical framework for narrative explanation in science. *Science Education, 89*, 535-563.

Ohlsson, S. (2002). Generating and understanding qualitative explanations. In J. Otero, J.A. Leon, & A. C. Graesser (Eds.), *The psychology of science text comprehension* (pp. 91-128). Mahwah, NJ: Erlbaum.

Pallant, J. (2007) SPSS survival manual: A step by step guide to data analysis using SPSS. (3rd ed.) St Leonards, NSW: Allen & Unwin,.

Petros, T. V., Norgaard, L., Olson, K., & Tabor, L. (1989). Effects of text genre and verbal ability on adult age differences in sensitivity to text structure. *Psychology and Aging, 4*, 247-250.

Piaget, J.-P. (1981). *Intelligence and affectivity*. New York: Basic Books.

Polkinghorne, D. E. (1988). Narrative knowing and the human sciences. Albany, NY: State University of New York Press.

Redish, E. & Steinberg, R. N. (1999). Teaching physics: Figuring out what works. *Physics Today, 52*, 24-30.

Sadoski, M., Goetz, E. T., & Fritz, J. (1993). Impact of concreteness on comprehensibility, interest, and memory for text: Implications for dual coding theory and text design. *Journal of Educational Psychology, 85*, 291-304.

Sadoski, M., Goetz, E. T., & Rodriguez, M. (2000). Engaging texts: Effects of concreteness on comprehensibility, interest, and recall in four text types. *Journal of Educational Psychology, 92*, 85-95.

Saenz, L. M. & Fuchs, L. S. (2002). Examining the reading difficulty of secondary students with learning disabilities: Expository versus narrative text. *Remedial and Special Education, 23*, 31-41.

Schank, R. (1990). *Tell Me a story; A new look at real and artificial memory*. New York: Charles Scribner.

Schank, R. and Berman, T. (2002). The pervasive role of stories in knowledge and action. In M.Green, J. Strange & T. Brock (Eds.), *Narrative impact* (pp. 287-313). New Jersey: Lawrence Erlbaum Associates, Inc.

Schank, R., Kass, A., & Riesbeck, C. (1994). *Inside case-based explanation*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Self-Determination Theory: An approach to human motivation and personality. (n.d.) Retreived September 17, 2007, from http://www.psych.rochester.edu/SDT/measures/intrins.html

Smithson, M. J. (2003). Scripts and software for noncentral confidence interval and power calculations [Computer software and manual]. Retrieved June 26, 2008, from http://psychology.anu.edu.au/people/smithson/details/CIstuff/CI.html

Solomon, J., Scott, L., & Duveen, J. (1996). Large-scale exploration of pupils' understanding of the nature of science. *Science Education, 80,* (493-508).

Stannard, R. (1989). *The time and space of uncle Albert.* New York: Henry Holt and Company.

Stannard, R. (2001). Communicating physics through story. *Physics Education, 36*, 30-34.

Stewart, I. (2001). *Flatterland*. Massachusetts: Perseus Publishing.

Tabachnick, B. G., & Fidell, L. S. (2007). Using multivariate statistics. (5th ed.) New York, NY: Harper Collins College Publishers.

Tamir, P. (1988). Gender differences in High School Science in Israel. *British Educational Research Journal, 14*, 127-140.

Tao, P. (2003). Eliciting and developing junior secondary students' understanding of the nature of science through a peer collaboration instruction in science stories. *International Journal of Science Education, 25*, 147-172.

Tun, P. A. (1989). Age differences in processing expository and narrative texts. *Journal of Gerontology: Psychological Sciences, 44*, 9-15.

Vasquez, D. (1997). *The effects of computer-game elements in physics instruction software for middle schools: A study on cognitive and affective gains.* Unpublished doctoral dissertation, University of San Francisco.

Wharton, W. (1980). Higher- imagery words and the readability of college history texts. *Journal of Mental Imagery, 4,* (129-147).

Wilson, E. O. (2002). The power of story. *American Educator, 26*, 8-11.

Yoder-Wise, P.S., Kowalski, K. (2003). The power of storytelling. *Nursing Outlook, 51*, 37-42.

Zabrucky, K. M., & Moore, D. (1999). Influence of text genre on adults' monitoring of understanding and recall. *Educational Gerontology, 25*, 691-710.

Zabrucky, K. M., & Ratner, H. H. (1992). Effects of passage type on comprehension monitoring and recall in good and poor readers. *Journal of Reading Behavior, 24*, 373-391.

Zelinski, E. M., & Gilewski, M. J. (1988). Memory for prose and aging: A meta-analysis. In M. L. Howe & C. J. Brainerd (Eds.), *Cognitive development in adulthood: Progress in cognitive development research* (pp. 133-158). New York: Springer-Verlag.

Zitzewski, P. W. (1999). *Glencoe physics: Principles and problems*. Westerville: Glencoe/McGraw Hill Publishing Company, Inc.

Appendix A: Instruction in Four Forms and Table of Differences

ABSTRACT COMMON

"You've got to throw out all common sense. . ." Her teacher was saying.

Hannah was taking a physics class this term and doing pretty OK, she thought. And now this -- Einstein's Special Theory of Relativity. Ugh. She rested her head on her hand and looked back at the teacher.

". . . relativity explains this paradox," he was saying. "Here's another paradox that helps illustrate his theory: Say you have a brand-new Lincoln Continental that you want to show off by driving at a substantial fraction of the speed of light into my garage. Now your car, at rest, is 12 feet long. My garage is also just 12 feet long. If you are moving very fast, however, I will measure your car to be only, say, 8 feet long. Thus there should be no problem fitting your car in my garage for a brief instant before either you hit the back wall or I open a door in the back of the garage to let you out. You, on the other hand, view me and my garage to be whizzing past you and thus to you my garage is only 8 feet long, while your car remains 12 feet long. Thus, it is impossible to fit your car in my garage.

"The miraculous thing about this paradox is, once again, that both of us are right. I indeed can close my garage door on you and have you in my garage for a moment. You, on the other hand, will feel yourself hit the back wall before I close the door.

"Nothing can be more real for either person, but as you can see, reality in this case is in the eye of the beholder. The point is that each person's *now* is subjective for distant events. The driver insists that *now* the front of his car is touching the back wall of the garage and the back is sticking out the front door, which is still open, while the garage owner insists that *now* the front door is closed and the front of the car has not yet reached the back wall. . ."[1]

Her eyes were glazing over. She could visualize what he had said about the garage and the car but the two different views of *now*? She was trying to stay focused but the warm, still air of the classroom, not to mention thoughts of her upcoming date on Saturday, made it hard to concentrate.

". . .to help you understand this, there is a homework assignment on the class website in Week 6. Download the broadcast and answer the questions in the assignment after you have listened to it. See you Thursday."

That evening when Hannah downloaded the broadcast, she heard a lively announcer introducing the program:

"Well folks, it's another beautiful day below ground here at the CERN particle accelerator on the French-Swiss border. This is John Cockcroft for Nuclear Physics Radio and today we'll be bringing you live coverage of the particle race of the century.

"It's a great day for a race and the track here is in excellent condition. For the folks at home who haven't had the chance to visit the site, let me describe what we are looking at: The particles will be racing through a circular hollow tube with a 17-mile circumference. Inside the tube, specially designed electromagnets will prevent the particles from careening off the track. Electric fields within the tubes will boost their speed along the way.

“Joining us is a good friend of mine and a renowned British physicist Ernie Walton. Ernie, thank you for joining us.”

“Thank you for having me.”

“I understand we will be seeing some important physics principles in the race today.”

“That’s right, John. What we will be looking at are part of Einstein’s Special Theory of Relativity. We will see length contraction, time dilation, mass increase, and mass energy exchange. It should be an exciting event.”

“We’ll be looking to you for more information throughout the race, Ernie. Ah. . . Our nuclear physicists are coming now into the observation room followed by their assistants and technicians. We have a number of charged particles at the gate waiting for the signal. . . AND THERE IT IS! THEY’RE OFF! The particles will circle the track millions of times picking up speed on each revolution as they race toward the speed of light.

“So tell us a little about Einstein’s theory, Ernie, while the particles get started.”

“The first thing I would have to say, John, is that you’ve got to forget about common sense. It will just confuse you when you think about Einstein’s work. The key word of his theory is relative. Everything is relative to the person observing. Everyone moves about in their own cubicle called a frame of reference.

“Einstein started with two postulates. First, *the laws of nature are the same for all observers who are in uniform motion*. So if you did an experiment while moving and maintaining a constant speed, your results would be the same as if you were standing motionless. This is where the “special” part of the theory comes in: it only works if you are in uniform motion. He says that uniform motion is impossible to detect. And it’s true. Did you know that you are going through space right now at about 67,000 miles an hour? Another example: think of a time when you weren’t sure if you were moving or if the objects around you were moving. Aside from the starting and stopping, can you tell that you are moving? So, measurements made in one frame of reference, Einstein says, are just as valid as measurements made in any other frame of reference, so long as everyone is in uniform motion.

“The second postulate is about the speed of light. He said that *the speed of light in empty space is the same for all observers regardless of their motion or the motion of the source of light*. For this to make sense, imagine that you are somewhere watching a wave moving away from you. As the wave moves across the water, it is quite possible for someone or something to pass it. Einstein’s postulate says that if this were a light wave, it would continue moving away from you, but it would not be possible to pass it no matter how fast you went. The light wave would always be moving ahead of you at the same speed: 186,000 miles per second. Even more interesting, a stationary observer in a different location would see it retreating at exactly the same speed. This is one of the places that common sense can confuse you. Common sense says that it’s like driving down the highway: someone passes you going 90 miles an hour. You decide that you can keep up with them and speed up to 85 miles an hour. You still see the car moving away from you but it takes the car much longer to get out of your sight. Well, with Einstein’s postulate, the car ahead of you would look like it did when you going 55 miles an hour and would be quickly out of sight. Light always goes the same speed no matter how fast you are going or which direction you are headed.

"This leads to another interesting idea called simultaneity. *The same event can be simultaneous for one person and not for another*. I'll give you the example Einstein liked to use. Suppose a train is moving in uniform motion at nearly the speed of light relative to an observer, M, standing by the tracks. The train, too, carries an observer, F, who is positioned at the midpoint of the train. The observers are motionless. Imagine lightning strikes both ends of the train when the two frames of reference are lined up. Each strike leaves a scorch mark on the train and on the ground, as well as emitting a pulse of light that begins traveling at large but finite speed toward the observers. At a later time F has moved with the train to the right and encounters the light pulse from the lightning strike on the right. M, however, is not yet aware of either strike, since the light has not reached her. At a later time, F has moved yet farther to the right, and M receives the two light pulses at the same instant. M measures off the distance between the scorch marks on the ground, finds herself to be at the midpoint, and concludes that the two events were "simultaneous". F, who has already observed the light pulse from the right, will eventually receive the pulse from the left. He measures the distance to the two scorch marks on the train and concludes he was at the midpoint between the strikes, but since F did not receive the two pulses coincidentally, he concludes the two events were "not simultaneous."

"Beware the temptation to use your common sense on this one! Common sense would say that the forward speed of the train caused the light from the front of the train to speed up. But Einstein's second postulate says this isn't so: light always travels at the same speed. Common sense would also tell us that it *really did* happen simultaneously and that the person M standing on the ground should know since she wasn't moving. But Einstein's first postulate says that isn't right because uniform motion is not detectable or definable. The person standing on the ground, remember, is also moving at high speeds with the earth. The fact is that the lightning strike was simultaneous to M but not to F. It's all relative."

"And this is the basis for the rest of the theory?"

"That's right. The interesting things we are going to see here today are caused by those two postulates and the special definition of simultaneity."

"What about the most famous part of Einstein's theory: $E=mc^2$? Could you tell us a little about that?"

"Sure, I'd be happy to. What the equation $E=mc^2$ means is Energy = mass x (speed of light)^2. Normally, you would think that the harder you pushed something, the faster it would go. What Einstein discovered is that there is a connection between mass and energy. As the accelerator here continues to push the particles along, the pushing energy converts into more mass for the particles. So, the closer the particles get to the speed of light, the more massive they become. . ."

". . .so the accelerator has to push harder which gives the particles even more mass? No wonder there's a speed limit. But, can it go the other way? Can mass become energy?"

"Yes, even small amounts of mass have incredible amounts of kinetic energy. The most familiar example of this is the atomic bomb. Nuclear reactors generate electricity from uranium. Another less well-known example of this is that sometimes the energy in light is enough to produce two electrons: one negatively charged and another positively charged. (The positively charged one is called a positron.) On the flip side, if a positron and an electron collide, their combined masses become light.

"Anytime you put energy into something and you don't see that energy expended, mass is increasing. For example, when you heat something, whatever you heat up will have more mass than it originally had."

"Well, with that in mind, let's take a look at how our particles are doing. They have been circling the accelerator here for some time and . . . Incredible as it sounds folks, the reports show that our little particles are gaining mass as they pick up speed. The physicists are having to continually boost the electromagnets and electric fields to push them along."

"That's the mass increase we are seeing there, John. As the particles approach the speed of light, their mass increases rapidly. The electric fields must work harder and harder to accelerate the particles. This is really noticeable going this fast but any acceleration increases mass, however minutely."

"How much mass increase are we talking about here with these particles? Is there a point where the electric fields won't be able to keep them accelerating?"

"Well, yes. Nothing can go the speed of light, except light. The particles will get heavier and heavier -- about 40,000 times heavier than normal and their acceleration will continue to slow. Nature sets a limit, you could say."

"So they won't be able to go the speed of light no matter how long they race?"

"That's right. They could get very close, but the closer they get the more difficult it will be to push them along. It's the difference between pushing something that weighs very little and something very heavy, really."

"Oh, now here's something else unusual. Our super-close-up observation cameras are showing the particles looking constricted. That may be just a problem with the video feed. Let me see if I can get our technicians to fix it."

"They won't be able to fix that, John. Even an electron can look a little constricted at these speeds. It's called length contraction. At 90% of the speed of light they appear less than half of their original length. We would really notice it if we were looking at much larger objects. Einstein explained that the length of a moving object gets shorter and shorter in the direction of motion the closer it gets to the speed of light. So, let's say you see an object and then you see the same object being shipped at nearly the speed of light. What you will see is an object that is just as tall as the object you saw earlier but not nearly as long as you think it ought to be. He even supposed that the length of an object becomes zero at the speed of light. But interestingly, if that were you, you wouldn't notice a thing."

"Really? I wouldn't be able to tell I was looking constricted?"

"No, you and everything moving with you would seem normal. In fact, if the particles could see us, they would say that *we* were the ones looking constricted."

"So does this only happen to things going close to the speed of light?"

"That's a good question. Einstein would say that even when you are moving at everyday speeds you'll experience a little mass increase and a little length contraction but the amount is very, very little and you never notice."

"Well, who would have thought? Woah! Folks, we have a late starter on the track. A muon has joined the race. We had a collision back there. . . the report is that a stray nitrogen nucleus was hit by a proton producing this new contestant. The muon is keeping up with the other particles going at 99% the speed of light. But how long can the muon keep this up? The lifetime of the muon is only two millionths of a second, not long enough to finish a lap. We should have already seen the decay, but no! It's still going! How is this possible Ernie?"

"To tell the truth John I was hoping we'd see something like this. Einstein called it time dilation. The particle is traveling at such high speeds that somehow its lifetime is extended tremendously. . ."

"And there's the decay: a couple of neutrinos and an electron. Still it made quite an impressive run."

"Yes, it did. It's been said that time slows down for moving objects but it's only significant when the speed approaches the speed of light. Einstein even speculated that when you are traveling at the speed of light, time stops! To test this theory out, a couple of scientists, Hafele and Keating put some atomic clocks on commercial jet airlines and flew them around the world. When they retrieved the clocks they compared them to the clocks that stayed at home and found a difference. It was a really small difference, something like 100 billionths of a second, but the clocks that were on the airplanes were definitely slower."

"This all reminds me of a science fiction story, I read. There were some people who went into space so they could live longer. When they finally returned, they were 25 years younger than their friends who were still alive. But they didn't feel like time was going slower. It seemed the same to them."

"Exactly. Those kinds of stories get their ideas from Einstein. If those people had remained in relative uniform motion we wouldn't see this effect because we wouldn't be able to compare them with their stay-at-home friends. They would have continued on their journey with their clocks ticking away as usual. If they could have caught a glimpse of earth, they would have seen earth clocks ticking very slowly, not only that but things on earth would look constricted and their measurements of mass would show everything as more massive. And vice versa, people on earth would see the same effects if they looked into the traveler's space ship.

"We see an age difference when the space traveling people return to earth precisely because they *did* return to earth. It is because they underwent acceleration and came home again that we can compare them and see an age difference. It is because the space travelers underwent acceleration and came home again and we can compare them that we see an age difference. It's like traveling two different routes to the same destination in space-time but it's the clock you carry with you that measures the separation of events."

"Hmm. That is interesting. OK, now thinking about the muon again, it seems like what you've been saying during the program is that if a muon could go the speed of light, it would last forever and its length would be zero AND it would be incredibly massive?"

"That's what we think would happen but we haven't been able to test it because only light can go the speed of light. However, it certainly is fun to think about."

"Einstein's theory certainly has a lot of the unexpected in it, doesn't it Ernie?"

"Yes, it does and the idea of simultaneity and his two postulates helped him figure out everything else we've seen here."

"I'm afraid that's all we have time for on our show today. Thank you for joining us. That wraps it up for us here at CERN. This is John Cockcroft of Nuclear Physics Radio signing off. Good day."

Hannah had to admit that she was starting to find this crazy theory interesting. She opened the assignment file and read through the questions, hoping she would be able to answer them.

ABSTRACT INVERTED

"You've got to throw out all common sense. . ." Her teacher was saying.

Hannah was taking a physics class this term and doing pretty OK, she thought. And now this -- Einstein's Special Theory of Relativity. Ugh. She rested her head on her hand and looked back at the teacher.

". . . relativity explains this paradox," he was saying. "Here's another paradox that helps illustrate his theory: Say you have a brand-new Lincoln Continental that you want to show off by driving at a substantial fraction of the speed of light into my garage. Now your car, at rest, is 12 feet long. My garage is also just 12 feet long. If you are moving very fast, however, I will measure your car to be only, say, 8 feet long. Thus there should be no problem fitting your car in my garage for a brief instant before either you hit the back wall or I open a door in the back of the garage to let you out. You, on the other hand, view me and my garage to be whizzing past you and thus to you my garage is only 8 feet long, while your car remains 12 feet long. Thus, it is impossible to fit your car in my garage.

"The miraculous thing about this paradox is, once again, that both of us are right. I indeed can close my garage door on you and have you in my garage for a moment. You, on the other hand, will feel yourself hit the back wall before I close the door.

"Nothing can be more real for either person, but as you can see, reality in this case is in the eye of the beholder. The point is that each person's *now* is subjective for distant events. The driver insists that *now* the front of his car is touching the back wall of the garage and the back is sticking out the front door, which is still open, while the garage owner insists that *now* the front door is closed and the front of the car has not yet reached the back wall. . ."

Her eyes were glazing over. She could visualize what he had said about the garage and the car but the two different views of *now*? She was trying to stay focused but the warm, still air of the classroom, not to mention thoughts of her upcoming date on Saturday, made it hard to concentrate.

". . .to help you understand this, there is a homework assignment on the class website in Week 6. Download the broadcast and answer the questions in the assignment after you have listened to it. See you Thursday."

That evening when Hannah downloaded the broadcast, she heard a lively announcer introducing the program:

"Well folks, it's another beautiful day below ground here at the CERN particle accelerator on the French-Swiss border. This is John Cockcroft for Nuclear Physics Radio and today we'll be bringing you live coverage of the particle race of the century."

"Joining us is a good friend of mine and a renowned British physicist Ernie Walton. Ernie, thank you for joining us."

"Thank you for having me."

"I understand we will be seeing some important physics principles in the race today."

"That's right, John. What we will be looking at are part of Einstein's Special Theory of Relativity. We will see length contraction, time dilation, mass increase, and mass energy exchange. It should be an exciting event."

"We'll be looking to you for more information throughout the race, Ernie. Ah. . . Our nuclear physicists are coming now into the observation room followed by their assistants and technicians. We have a number of charged particles at the gate waiting for the signal. . . AND THERE IT IS! THEY'RE OFF!

"It's a great day for a race and the track here is in excellent condition. For the folks at home who haven't had the chance to visit the site, let me describe what we are looking at: The particles will be racing through a circular hollow tube with a 17-mile circumference. Inside the tube, specially designed electromagnets will prevent the particles from careening off the track. Electric fields within the tubes will boost their speed along the way. The particles will circle the track millions of times picking up speed on each revolution as they race toward the speed of light.

"Well, let's take a look at how our particles are doing. They have been circling the accelerator here for a little while and . . . Incredible as it sounds folks, the reports show that the particles are gaining mass as they pick up speed. The physicists are having to continually boost the electromagnets and electric fields to push them along."

"That's the mass increase we are seeing there, John. As the particles approach the speed of light, their mass increases rapidly. The electric fields must work harder and harder to accelerate the particles. This is really noticeable going this fast but any acceleration increases mass, however minutely."

"How much mass increase are we talking about here with these particles? Is there a point where the electric fields won't be able to keep them accelerating?"

"Well, yes. Nothing can go the speed of light, except light. The particles will get heavier and heavier -- about 40,000 times heavier than normal and their acceleration will continue to slow. Nature sets a limit, you could say."

"So they won't be able to go the speed of light no matter how long they race?"

"That's right. They could get very close, but the closer they get the more difficult it will be to push them along. It's the difference between pushing something that weighs very little and something very heavy, really."

"Oh, now here's something else unusual. Our super-close-up observation cameras are showing the particles looking constricted. That may be just a problem with the video feed. Let me see if I can get our technicians to fix it."

"They won't be able to fix that, John. Even an electron can look a little constricted at these speeds. It's called length contraction. At 90% of the speed of light they appear less than half of their original length. We would really notice it if we were looking at much larger objects. Einstein explained that the length of a moving object gets shorter and shorter in the direction of motion the closer it gets to the speed of light. So, let's say you see an object and then you see the same object being shipped at nearly the speed of light. What you will see is an object that is just as tall as the object you saw earlier but not nearly as long as you think it ought to be. He even supposed that the length of an object becomes zero at the speed of light. But interestingly, if that were you, you wouldn't notice a thing."

"Really? I wouldn't be able to tell I was looking constricted?"

"No, you and everything moving with you would seem normal. In fact, if the particles could see us, they would say that *we* were the ones looking constricted."

"So does this only happen to things going close to the speed of light?"

"That's a good question. Einstein would say that even when you are moving at everyday speeds you'll experience a little mass increase and a little length contraction but the amount is very, very little and you never notice."

"Well, who would have thought? Woah! Folks, we have a late starter on the track. A muon has joined the race. We had a collision back there. . . the report is that a stray nitrogen nucleus was hit by a proton producing this new contestant. The muon is keeping up with the other particles going at 99% the speed of light. But how long can the muon keep this up? The lifetime of the muon is only two millionths of a second, not long enough to finish a lap. We should have already seen the decay, but no! It's still going! How is this possible Ernie?"

"To tell the truth John I was hoping we'd see something like this. Einstein called it time dilation. The particle is traveling at such high speeds that somehow its lifetime is extended tremendously. . ."

"And there's the decay: a couple of neutrinos and an electron. Still it made quite an impressive run."

"Yes, it did. It's been said that time slows down for moving objects but it's only significant when the speed approaches the speed of light. Einstein even speculated that when you are traveling at the speed of light, time stops! To test this theory out, a couple of scientists, Hafele and Keating put some atomic clocks on commercial jet airlines and flew them around the world. When they retrieved the clocks they compared them to the clocks that stayed at home and found a difference. It was a really small difference, something like 100 billionths of a second, but the clocks that were on the airplanes were definitely slower."

"This all reminds me of a science fiction story, I read. There were some people who went into space so they could live longer. When they finally returned, they were 25 years younger than their friends who were still alive. But they didn't feel like time was going slower. It seemed the same to them."

"Exactly. Those kinds of stories get their ideas from Einstein. If those people had remained in relative uniform motion we wouldn't see this effect because we wouldn't be able to compare them with their stay-at-home friends. They would have continued on their journey with their clocks ticking away as usual. If they could have caught a glimpse of earth, they would have seen earth clocks ticking very slowly, not only that but things on earth would look constricted and their measurements of mass would show everything as more massive. And vice versa, people on earth would see the same effects if they looked into the traveler's space ship.

"We see an age difference when the space traveling people return to earth precisely because they *did* return to earth. It is because they underwent acceleration and came home again that we can compare them and see an age difference. It is because the space travelers underwent acceleration and came home again and we can compare them that we see an age difference. It's like traveling two different routes to the same destination in space-time but it's the clock you carry with you that measures the separation of events."

"Aside from all the science fiction stuff, Ernie, it seems that the most famous part of Einstein's theory is $E=mc^2$. Could you tell us a little about that?"

"Sure, I'd be happy to. What the equation $E=mc^2$ means is Energy = mass x (speed of light)^2. Remember how we talked about the particles increasing in mass the faster they went? Well, this is the reason why that happens. Normally, you would think that the harder you pushed something, the faster it would go. What Einstein discovered is that there is a connection between mass and energy. As the accelerator here continues to push the particles along, the pushing energy converts into more mass for the particles. So, the closer the particles get to the speed of light, the more massive they become. . ."

". . .So the accelerator has to push harder which gives the particles even more mass? No wonder there's a limit. But, can it go the other way? Can mass become energy?"

"Yes, even small amounts of mass have incredible amounts of kinetic energy. The most familiar example of this is the atomic bomb. Nuclear reactors generate electricity from uranium. Another less well-known example of this is that sometimes the energy in light is adequate to produce two electrons: one negatively charged and another positively charged. (The positively charged one is called a positron.) On the flip side, if a positron and an electron collide, their combined masses become light."

"Anytime you put energy into something and you don't see that energy expended, mass is increasing. For example, when you heat something, whatever you heat up will have more mass than it originally had."

"Hmm. That is interesting. OK, now thinking about the muon again, it seems like what you've been saying during the program is that if a muon could go the speed of light, it would last forever and its length would be zero AND it would be incredibly massive?"

"That's what we think would happen but we haven't been able to test it because only light can go the speed of light. However, it certainly is fun to think about."

"Einstein's theory certainly has a lot of the unexpected in it. Is there more to Einstein's theory than we've seen here?"

"Oh yes, there's the idea of simultaneity and his two postulates that helped him figure out everything else. The first thing I would have to say, John, before talking about these ideas is that you've got to forget about common sense. It will just confuse you when you think about Einstein's work. The key word of his theory is *relative*. Everything is relative to the person observing. Everyone moves about in their own cubicle called a frame of reference.

"Einstein started with two postulates. First, *the laws of nature are the same for all observers who are in uniform motion*. So if you did an experiment while moving and maintaining a constant speed, your results would be the same as if you were standing motionless. This is where the "special" part of the theory comes in: it only works if you are in uniform motion. He says that uniform motion is impossible to detect. And it's true. Did you know that you are going through space right now at about 67,000 miles an hour? Another example: think of a time when you weren't sure if you were moving or if the objects around you were moving. Aside from the starting and stopping, can you tell that you are moving? So, measurements made in one frame of reference, Einstein says, are just as valid as measurements made in any other frame of reference, so long as everyone is in uniform motion.

"The second postulate is about the speed of light. He said that *the speed of light in empty space is the same for all observers regardless of their motion or the motion of the source of light*. For this to make sense, imagine that you are somewhere watching a wave moving away from you. As the wave moves across the water, it is quite possible for someone or something to pass it. Einstein's postulate says that if this were a light wave, it would continue moving away from you, but it would not be possible to pass it no matter how fast you went. The light wave would always be moving ahead of you at the same speed: 186,000 miles per second. Even more interesting, a stationary observer in a different location would see it retreating at exactly the same speed. This is one of the places that common sense can confuse you. Common sense says that it's like driving down the highway: someone passes you going 90 miles an hour. You decide that you can keep up with them and speed up to 85 miles an hour. You still see the car moving away from you but it takes the car much longer to get out of your sight. Well, with Einstein's postulate, the car ahead of you would look like it did when you going 55 miles an hour and would be quickly out of sight. Light always goes the same speed no matter how fast you are going or which direction you are headed.

"This leads to another interesting idea called simultaneity. *The same event can be simultaneous for one person and not for another*. I'll give you the example Einstein liked to use. Suppose a train is moving in uniform motion at nearly the speed of light relative to an observer, M, standing by the tracks. The train, too, carries an observer, F, who is positioned at the midpoint of the train. The observers are motionless. Imagine lightning strikes both ends of the train when the two frames of reference are lined up. Each strike leaves a scorch mark on the train and on the ground, as well as emitting a pulse of light that begins traveling at large but finite speed toward the observers. At a later time F has moved with the train to the right and encounters the light pulse from the lightning strike on the right. M, however, is not yet aware of either strike, since the light has not reached her. At a later time, F has moved yet farther to the right, and M receives the two light pulses at the same instant. M measures off the distance between the scorch marks on the ground, finds herself to be at the midpoint, and concludes that the two events were "simultaneous". F, who has already observed the light pulse from the right, will eventually receive the pulse from the left. He measures the distance to the two scorch marks on the train and concludes he was at the midpoint between the strikes, but since F did not receive the two pulses coincidentally, he concludes the two events were "not simultaneous."

"Beware the temptation to use your common sense on this one! Common sense would say that the forward speed of the train caused the light from the front of the train to speed up. But Einstein's second postulate says this isn't so: light always travels at the same speed. Common sense would also tell us that it *really did* happen simultaneously and that the person M standing on the ground should know since she wasn't moving. But Einstein's first postulate says that isn't right because uniform motion is not detectable or definable. The person standing on the ground, remember, is also moving at high speeds with the earth. The fact is that the lightning strike was simultaneous to M but not to F. It's all relative."

"And this is the basis for the rest of the theory?"

"That's right. These two postulates, the idea of simultaneity and the mass – energy exchange principle are what caused all the interesting things we saw here today."

"Thank you for joining us. That wraps it up for us here at CERN. This is John Cockcroft of Nuclear Physics Radio signing off. Good day."

Hannah had to admit that she was starting to find this crazy theory interesting. She opened the assignment file and read through the questions, hoping she would be able to answer them.

CONCRETE COMMON

"You've got to throw out all common sense. . ." Her teacher was saying.

Hannah was taking a physics class this term and doing pretty OK, she thought. And now this -- Einstein's Special Theory of Relativity. Ugh. She rested her head on her hand and looked back at the teacher.

". . . relativity explains this paradox," he was saying. "Here's another paradox that helps illustrate his theory: Say you have a brand-new Lincoln Continental that you want to show off by driving at a substantial fraction of the speed of light into my garage. Now your car, at rest, is 12 feet long. My garage is also just 12 feet long. If you are moving very fast, however, I will measure your car to be only, say, 8 feet long. Thus there should be no problem fitting your car in my garage for a brief instant before either you hit the back wall or I open a door in the back of the garage to let you out. You, on the other hand, view me and my garage to be whizzing past you and thus to you my garage is only 8 feet long, while your car remains 12 feet long. Thus, it is impossible to fit your car in my garage.

"The miraculous thing about this paradox is, once again, that both of us are right. I indeed can close my garage door on you and have you in my garage for a moment. You, on the other hand, will feel yourself hit the back wall before I close the door.

"Nothing can be more real for either person, but as you can see, reality in this case is in the eye of the beholder. The point is that each person's *now* is subjective for distant events. The driver insists that *now* the front of his car is touching the back wall of the garage and the back is sticking out the front door, which is still open, while the garage owner insists that *now* the front door is closed and the front of the car has not yet reached the back wall. . ."

Her eyes were glazing over. She could visualize what he had said about the garage and the car but the two different views of *now*? She was trying to stay focused but the warm, still air of the classroom, not to mention thoughts of her upcoming date on Saturday, made it hard to concentrate.

". . .to help you understand this, there is a homework assignment on the class website in Week 6. Download the broadcast and answer the questions in the assignment after you have listened to it. See you Thursday."

That evening when Hannah downloaded the broadcast, she heard a lively announcer introducing the program:

"Well folks, it's another beautiful day below ground here at the CERN particle accelerator on the French-Swiss border. This is John Cockcroft for Nuclear Physics Radio and today we'll be bringing you live coverage of the particle race of the century.

"It's a great day for a race and the track here is in excellent condition. For the folks at home who haven't had the chance to visit the site, let me describe what we are looking at: The particles will be racing through a circular hollow tube with a 17-mile circumference. Inside the tube, specially designed electromagnets will prevent the particles from careening off the track. Electric fields within the tubes will boost their speed along the way.

"Joining us is a good friend of mine and a renowned British physicist Ernie Walton. Ernie, thank you for joining us."

"Thank you for having me."

"I understand we will be seeing some important physics principles in the race today."

"That's right, John. What we will be looking at are part of Einstein's Special Theory of Relativity. We will see length contraction, time dilation, mass increase, and mass energy exchange. It should be an exciting event."

"We'll be looking to you for more information throughout the race, Ernie. Ah. . . Our nuclear physicists are coming now into the observation room followed by their assistants and technicians. We have a number of charged particles at the gate waiting for the signal. . . AND THERE IT IS! THEY'RE OFF! The particles will circle the track millions of times picking up speed on each revolution as they race toward the speed of light.

"So tell us a little about Einstein's theory, Ernie, while the particles get started."

"The first thing I would have to say, John, is that you've got to forget about common sense. It will just confuse you when you think about Einstein's work. The key word of his theory is relative. Everything is relative to the person observing. Everyone moves about in their own cubicle called a frame of reference.

"Einstein started with two postulates. First, *the laws of nature are the same for all observers who are in uniform motion*. So if you did an experiment on a train that was maintaining 120 mph, your results would be the same as if you were standing next to the tracks. This is where the "special" part of the theory comes in: it only works if you are in uniform motion. He says that uniform motion is impossible to detect. And it's true. Did you know that you are flying through space right now at about 67,000 miles an hour? Another example: think of riding in an elevator. Aside from the starting and stopping, can you tell that you are moving? So, measurements made in Sally's frame of reference, Einstein says, are just as valid as measurements made in Jenny or Ben's frame of reference, so long as everyone is in uniform motion.

"The second postulate is about the speed of light. He said that *the speed of light in empty space is the same for all observers regardless of their motion or the motion of the source of light*. For this to make sense, imagine that you are in a speedboat on Lake Powell and you see a wave moving away from you. You want to pass it up so you accelerate and quickly pass the wave. Einstein's postulate says that if this were a light wave, you would see it moving away from you, but even if you had super jet propulsion that could get you almost to the speed of light, the light wave would always be moving ahead of you at the same speed: 186,000 miles per second. Even more interesting, the kid in the inner tube near the shore would see it retreating at exactly the same speed. This is one of the places that common sense can confuse you. Common sense says that it's like driving down the highway: a red sports car passes you up going 90 miles an hour. You decide that you can keep up with them and speed up to 85 miles an hour. You still see the sports car moving away from you but it takes much longer to get out of your sight. Well, with Einstein's postulate, the sports car would look like it did when you going 55 miles an hour and would be quickly out of sight. Light always goes the same speed no matter how fast you are going or which direction you are going.

"This leads to another interesting idea called simultaneity. *The same event can be simultaneous for one person and not for another*. I'll give you the example Einstein liked to use. Suppose a train is moving in uniform motion at nearly the speed of light relative to Marie who is standing by the tracks. The train, too, carries an observer, Fred, who is standing at the midpoint of the train. Fred and Marie are motionless. Imagine lightning strikes both ends of the train when Fred and Marie are exactly across from each other. Each strike leaves a scorch mark on the train and on the ground, as well as emitting a pulse of light that begins traveling at large but finite speed toward Fred and Marie. At a later time Fred has moved with the train to the right and encounters the light pulse from the lightning strike on the right. Marie, however, is not yet aware of either strike, since the light has not reached her. At a later time, Fred has moved yet farther to the right, and Marie receives the two light pulses at the same instant. Marie measures off the distance between the scorch marks on the ground, finds herself to be at the midpoint and concludes that the two events were "simultaneous." Fred, who has already observed the light pulse from the right, will eventually receive the pulse from the left. He measures the distance to the two scorch marks on the train and concludes he was at the midpoint between the strikes but since Fred did not receive the two pulses coincidentally, he concludes the two events were not simultaneous."

"Beware the temptation to use your common sense on this one! Common sense would say that the forward speed of the train caused the light from the front of the train to speed up. But Einstein's second postulate says this isn't so: light always travels at the same speed. Common sense would also tell us that it *really did* happen simultaneously and that Marie, who is standing on the ground, should know since she wasn't moving. But Einstein's first postulate says that isn't right because uniform motion is not detectable or definable. The person standing on the ground, remember, is also moving at high speeds with the earth. The fact is that the lightning strike was simultaneous to Marie but not to Fred. It's all relative."

"And this is the basis for the rest of the theory?"

"That's right. The interesting things we are going to see here today are caused by those two postulates and the special definition of simultaneity."

"What about the most famous part of Einstein's theory: $E=mc^2$? Could you tell us a little about that?"

"Sure, I'd be happy to. What the equation $E=mc^2$ means is Energy = mass x (speed of light)^2. Remember how we talked about the particles increasing in mass the faster they went? Well, this is the reason why that happens. Normally, you would think that the harder you pushed an object, the faster it would go. What Einstein discovered is that there is a connection between mass and energy. As the accelerator here keeps shoving the particles forward, the pushing energy transforms into more mass for the particles. So, the closer the particles get to the speed of light, the more massive they grow. . ."

“. . .so the accelerator has to push harder which gives the particles even more mass? No wonder there’s a speed limit. But, can it go the other way? Can mass become energy?”

“Yes, even small amounts of mass have incredible amounts of kinetic energy. The most familiar example of this is the atomic bomb. Nuclear reactors generate electricity from uranium. Another less well-known example of this is that sometimes the energy in light is enough to produce two electrons: one negatively charged and another positively charged. (The positively charged one is called a positron.) On the flip side, if a positron and an electron collide, their combined masses become light.

“Anytime you put energy into a system and you don’t see that energy expended, mass is increasing. For example, when you warm tortillas in the oven, the tortillas will have more mass when you take them out than they did when you put them in.”

“Well, with that in mind, let’s take a look at how our particles are doing. They have been circling the accelerator here for some time and . . . Incredible as it sounds folks, the reports show that the little particles are gaining mass as they pick up speed. The physicists are having to continually boost the electromagnets and electric fields to push them along.”

“That’s the mass increase we are seeing there, John. As the particles approach the speed of light, their mass increases rapidly. The electric fields must work harder and harder to accelerate the particles.”

“How much mass increase are we talking about here? Is there a point where the electric fields won’t be able to keep them accelerating?”

“Well, yes. Nothing can go the speed of light, except light. Some of the energy that’s pushing them gets converted into mass. So the particles will get heavier and heavier -- about 40,000 times heavier than normal and their acceleration will continue to slow. Nature sets a speed limit, you could say.”

“So they won’t be able to go the speed of light no matter how long they race?”

“That’s right. They could get very close, but the closer they get the more difficult it will be to push them along. It’s the difference between pushing a wooden toy car and a stretch limousine, really.”

“Oh, now here’s something else unusual. Our super-close-up observation cameras are showing the particles looking slightly squished. That may be just a problem with the video feed. Let me see if I can get our technicians to fix it.”

“They won’t be able to fix that, John. Even an electron can look a little squished at these speeds. It’s called length contraction. At 90% of the speed of light they appear less than half of their original length. We would really notice it if we were looking at, say, a cruise ship. Einstein explained that the length of a moving object gets shorter and shorter in the direction of motion the closer it gets to the speed of light. So, let’s say you get a glimpse of your large, beautifully wrapped Christmas present and then you see it being shipped at nearly the speed of light. What you will see is a package that is just as tall as the gift you saw earlier but not nearly as long as you think it ought to be. He even supposed that the length of the gift becomes zero at the speed of light. But interestingly, if that were you, you wouldn’t notice a thing.”

“Really? I wouldn’t be able to tell I was looking squished?”

“No, you and everything moving with you would seem normal. In fact, if the particles could see us, they would say that *we* were the ones looking squished.”

"So does this only happen to things going close to the speed of light?"

"That's a good question. Einstein would say that even when you are running, riding a bike or flying in an airplane you'll experience a little mass increase and a little length contraction but the amount is very, very little and you never notice."

"Well, who would have thought? Woah! Folks, we have a late starter on the track. A muon has joined the race. We had a collision back there. . . the report is that a stray nitrogen nucleus was hit by a proton producing this new contestant. The muon is keeping up with the other particles going at 99% the speed of light. But how long can the muon keep this up? The lifetime of the muon is only two millionths of a second, not long enough to finish a lap. We should have already seen the decay, but no! It's still going! How is this possible Ernie?"

"To tell the truth John I was hoping we'd see something like this. Einstein called it time dilation. The particle is traveling at such high speeds that somehow its lifetime is extended tremendously."

"And there's the decay: a couple of neutrinos and an electron. Still it made quite an impressive run."

"Yes, it did. It's been said that time slows down for moving objects but it's only obvious when the speed approaches the speed of light. Einstein even speculated that when you are traveling at the speed of light, time stops! To test this theory out, a couple of scientists, Hafele and Keating put some atomic clocks on commercial jet airlines and flew them around the world. When they retrieved the clocks they set them next to the clocks that stayed at home and found a difference. It was a really small difference, something like 100 billionths of a second, but the clocks that were on the airplanes were definitely slower."

"This all reminds me of a science fiction story, I read. There were some little grandmas who went into space so they could live longer. When they finally returned, they were 25 years younger than their friends who were still alive. But they didn't feel like time was going slower. It seemed the same to them."

"Exactly. Those kinds of stories get their ideas from Einstein. If those grandmas had remained in relative uniform motion we wouldn't see this effect because we wouldn't be able to see them standing next to their stay-at-home friends. They would have continued on their journey with their clocks ticking away as usual. If they could have caught a glimpse of earth, they would have seen earth clocks ticking very slowly, not only that, but things on earth would look squished and their measurements of mass would show everything as more massive. And vice versa, their friends on earth would see the same effects if they looked into the grandmas' space ship.

"We see an age difference when the space traveling grandmas return to earth precisely because they *did* return to earth. It is because they underwent acceleration and came home again that we can compare them and see an age difference. It's like driving two different routes to the same destination in spacetime but it's the clock you carry with you that measures the separation of events."

"Hmm. That is interesting. OK, now thinking about the muon again, it seems like what you've been saying during the program is that if a muon could go the speed of light, it would last forever and its length would be zero AND it would be incredibly massive?"

"That's what we think would happen but we haven't been able to test it because only light can go the speed of light. However, it certainly is fun to think about."

"Einstein's theory certainly has a lot of the unexpected in it, doesn't it Ernie?"

"Yes, it does and the idea of simultaneity and his two postulates helped him figure out everything else we've seen here."

"I'm afraid that's all we have time for on our show today. Thank you for joining us. That wraps it up for us here at CERN. This is John Cockcroft of Nuclear Physics Radio signing off. Good day."

Hannah had to admit that she was starting to find this crazy theory interesting. She opened the assignment file and read through the questions, hoping she would be able to answer them.

CONCRETE INVERTED

"You've got to throw out all common sense. . ." Her teacher was saying.

Hannah was taking a physics class this term and doing pretty OK, she thought. And now this -- Einstein's Special Theory of Relativity. Ugh. She rested her head on her hand and looked back at the teacher.

". . . relativity explains this paradox," he was saying. "Here's another paradox that helps illustrate his theory: Say you have a brand-new Lincoln Continental that you want to show off by driving at a substantial fraction of the speed of light into my garage. Now your car, at rest, is 12 feet long. My garage is also just 12 feet long. If you are moving very fast, however, I will measure your car to be only, say, 8 feet long. Thus there should be no problem fitting your car in my garage for a brief instant before either you hit the back wall or I open a door in the back of the garage to let you out. You, on the other hand, view me and my garage to be whizzing past you and thus to you my garage is only 8 feet long, while your car remains 12 feet long. Thus, it is impossible to fit your car in my garage.

"The miraculous thing about this paradox is, once again, that both of us are right. I indeed can close my garage door on you and have you in my garage for a moment. You, on the other hand, will feel yourself hit the back wall before I close the door.

"Nothing can be more real for either person, but as you can see, reality in this case is in the eye of the beholder. The point is that each person's *now* is subjective for distant events. The driver insists that *now* the front of his car is touching the back wall of the garage and the back is sticking out the front door, which is still open, while the garage owner insists that *now* the front door is closed and the front of the car has not yet reached the back wall. . ."

Her eyes were glazing over. She could visualize what he had said about the garage and the car but the two different views of *now*? She was trying to stay focused but the warm, still air of the classroom, not to mention thoughts of her upcoming date on Saturday, made it hard to concentrate.

". . .to help you understand this, there is a homework assignment on the class website in Week 6. Download the broadcast and answer the questions in the assignment after you have listened to it. See you Thursday."

That evening when Hannah downloaded the broadcast, she heard a lively announcer introducing the program:

"Well folks, it's another beautiful day below ground here at the CERN particle accelerator on the French-Swiss border. This is John Cockcroft for Nuclear Physics Radio and today we'll be bringing you live coverage of the particle race of the century.

"Joining us is a good friend of mine and a renowned British physicist Ernie Walton. Ernie, thank you for joining us."

"Thank you for having me."

"I understand we will be seeing some important physics principles in the race today."

"That's right, John. What we will be looking at are part of Einstein's Special Theory of Relativity. We will see length contraction, time dilation, mass increase, and mass energy exchange. It should be an exciting event."

"We'll be looking to you for more information throughout the race, Ernie. Ah. . . Our nuclear physicists are coming now into the observation room followed by their assistants and technicians. We have a number of charged particles at the gate waiting for the signal. . . AND THERE IT IS! THEY'RE OFF!"

"It's a great day for a race and the track here is in excellent condition. For the folks at home who haven't had the chance to visit the site, let me describe what we are looking at: The particles will be racing through a circular hollow tube with a 17-mile circumference. Inside the tube, specially designed electromagnets will prevent the particles from careening off the track. Electric fields within the tubes will boost their speed along the way. The particles will circle the track millions of times picking up speed on each revolution as they race toward the speed of light."

"Well, let's take a look at how our particles are doing. They have been circling the accelerator here for a little while and . . . Incredible as it sounds folks, the reports show that the little particles are gaining mass as they pick up speed. The physicists are having to continually boost the electromagnets and electric fields to push them along."

"That's the mass increase we are seeing there, John. As the particles approach the speed of light, their mass increases rapidly. The electric fields must work harder and harder to accelerate the particles."

"How much mass increase are we talking about here? Is there a point where the electric fields won't be able to keep them accelerating?"

"Well, yes. Nothing can go the speed of light, except light. Some of the energy that's pushing them gets converted into mass. So the particles will get heavier and heavier -- about 40,000 times heavier than normal and their acceleration will continue to slow. Nature sets a speed limit, you could say."

"So they won't be able to go the speed of light no matter how long they race?"

"That's right. They could get very close, but the closer they get the more difficult it will be to push them along. It's the difference between pushing a wooden toy car and a stretch limousine, really."

"Oh, now here's something else unusual. Our super-close-up observation cameras are showing the particles looking slightly squished. That may be just a problem with the video feed. Let me see if I can get our technicians to fix it."

"They won't be able to fix that, John. Even an electron can look a little squished at these speeds. It's called length contraction. At 90% of the speed of light they appear less than half of their original length. We would really notice it if we were looking at, say, a cruise ship. Einstein explained that the length of a moving object gets shorter and shorter in the direction of motion the closer it gets to the speed of light. So, let's say you get a glimpse of your large, beautifully wrapped Christmas present and then you see it being shipped at nearly the speed of light. What you will see is a package that is just as tall as the gift you saw earlier but not nearly as long as you think it ought to be. He even supposed that the length of the gift becomes zero at the speed of light. But interestingly, if that were you, you wouldn't notice a thing."

"Really? I wouldn't be able to tell I was looking squished?"

"No, you and everything moving with you would seem normal. In fact, if the particles could see us, they would say that *we* were the ones looking squished."

"So does this only happen to things going close to the speed of light?"

"That's a good question. Einstein would say that even when you are running, riding a bike or flying in an airplane you'll experience a little mass increase and a little length contraction but the amount is very, very little and you never notice."

"Well, who would have thought? Woah! Folks, we have a late starter on the track. A muon has joined the race. We had a collision back there. . . the report is that a stray nitrogen nucleus was hit by a proton producing this new contestant. The muon is keeping up with the other particles going at 99% the speed of light. But how long can the muon keep this up? The lifetime of the muon is only two millionths of a second, not long enough to finish a lap. We should have already seen the decay, but no! It's still going! How is this possible Ernie?"

"To tell the truth John I was hoping we'd see something like this. Einstein called it time dilation. The particle is traveling at such high speeds that somehow its lifetime is extended tremendously."

"And there's the decay: a couple of neutrinos and an electron. Still it made quite an impressive run."

"Yes, it did. It's been said that time slows down for moving objects but it's only obvious when the speed approaches the speed of light. Einstein even speculated that when you are traveling at the speed of light, time stops! To test this theory out, a couple of scientists, Hafele and Keating put some atomic clocks on commercial jet airlines and flew them around the world. When they retrieved the clocks they set them next to the clocks that stayed at home and found a difference. It was a really small difference, something like 100 billionths of a second, but the clocks that were on the airplanes were definitely slower."

"This all reminds me of a science fiction story, I read. There were some little grandmas who went into space so they could live longer. When they finally returned, they were 25 years younger than their friends who were still alive. But they didn't feel like time was going slower. It seemed the same to them."

"Exactly. Those kinds of stories get their ideas from Einstein. If those grandmas had remained in relative uniform motion we wouldn't see this effect because we wouldn't be able to see them standing next to their stay-at-home friends. They would have continued on their journey with their clocks ticking away as usual. If they could have caught a glimpse of earth, they would have seen earth clocks ticking very slowly, not only that, but things on earth would look squished and their measurements of mass would show everything as more massive. And vice versa, their friends on earth would see the same effects if they looked into the grandmas' space ship.

"We see an age difference when the space traveling grandmas return to earth precisely because they *did* return to earth. It is because they underwent acceleration and came home again that we can compare them and see an age difference. It's like driving two different routes to the same destination in spacetime but it's the clock you carry with you that measures the separation of events."

"Aside from all the science fiction stuff, Ernie, it seems that the most famous part of Einstein's theory is $E=mc^2$. Could you tell us a little about that?"

"Sure, I'd be happy to. What the equation $E=mc^2$ means is Energy = mass x (speed of light)^2. Remember how we talked about the particles increasing in mass the faster they went? Well, this is the reason why that happens. Normally, you would think that the harder you pushed an object, the faster it would go. What Einstein discovered is that there is a connection between mass and energy. As the accelerator here keeps shoving the particles forward, the pushing energy transforms into more mass for the particles. So, the closer the particles get to the speed of light, the more massive they grow. . ."

". . .so the accelerator has to push harder which gives the particles even more mass? No wonder there's a speed limit. But, can it go the other way? Can mass become energy?"

"Yes, even small amounts of mass have incredible amounts of kinetic energy. The most familiar example of this is the atomic bomb. Nuclear reactors generate electricity from uranium. Another less well-known example of this is that sometimes the energy in light is enough to produce two electrons: one negatively charged and another positively charged. (The positively charged one is called a positron.) On the flip side, if a positron and an electron collide, their combined masses become light.

"Anytime you put energy into a system and you don't see that energy expended, mass is increasing. For example, when you warm tortillas in the oven, the tortillas will have more mass when you take them out than they did when you put them in."

"Hmm. That is interesting. OK, now thinking about the muon again, it seems like what you've been saying during the program is that if a muon could go the speed of light, it would last forever and its length would be zero AND it would be incredibly massive?"

"That's what we think would happen but we haven't been able to test it because only light can go the speed of light. However, it certainly is fun to think about."

"Einstein's theory certainly has a lot of the unexpected in it. Is there more to Einstein's theory than we've seen here?"

"Oh yes, there's the idea of simultaneity and his two postulates that helped him figure out everything else. The first thing I would have to say, John, before talking about these ideas is that you've got to forget about common sense. It will just confuse you when you think about Einstein's work. The key word of his theory is *relative*. Everything is relative to the person observing. Everyone moves about in their own cubicle called a frame of reference.

"Einstein started with two postulates. First, *the laws of nature are the same for all observers who are in uniform motion*. So if you did an experiment on a train that was maintaining 120 mph, your results would be the same as if you were standing next to the tracks. This is where the "special" part of the theory comes in: it only works if you are in uniform motion. He says that uniform motion is impossible to detect. And it's true. Did you know that you are flying through space right now at about 67,000 miles an hour?

Another example: think of riding in an elevator. Aside from the starting and stopping, can you tell that you are moving? So, measurements made in Sally's frame of reference, Einstein says, are just as valid as measurements made in Jenny or Ben's frame of reference, so long as everyone is in uniform motion.

"The second postulate is about the speed of light. He said that *the speed of light in empty space is the same for all observers regardless of their motion or the motion of the source of light*. For this to make sense, imagine that you are in a speedboat on Lake Powell and you see a wave moving away from you. You want to pass it up so you accelerate and quickly pass the wave. Einstein's postulate says that if this were a light wave, you would see it moving away from you, but even if you had super jet propulsion that could get you almost to the speed of light, the light wave would always be moving ahead of you at the same speed: 186,000 miles per second. Even more interesting, the kid in the inner tube near the shore would see it retreating at exactly the same speed. This is one of the places that common sense can confuse you. Common sense says that it's like driving down the highway: a red sports car passes you up going 90 miles an hour. You decide that you can keep up with them and speed up to 85 miles an hour. You still see the sports car moving away from you but it takes much longer to get out of your sight. Well, with Einstein's postulate, the sports car would look like it did when you going 55 miles an hour and would be quickly out of sight. Light always goes the same speed no matter how fast you are going or which direction you are going.

"This leads to another interesting idea called simultaneity. *The same event can be simultaneous for one person and not for another*. I'll give you the example Einstein liked to use. Suppose a train is moving in uniform motion at nearly the speed of light relative to Marie who is standing by the tracks. The train, too, carries an observer, Fred, who is standing at the midpoint of the train. Fred and Marie are motionless. Imagine lightning strikes both ends of the train when Fred and Marie are exactly across from each other. Each strike leaves a scorch mark on the train and on the ground, as well as emitting a pulse of light that begins traveling at large but finite speed toward Fred and Marie. At a later time Fred has moved with the train to the right and encounters the light pulse from the lightning strike on the right. Marie, however, is not yet aware of either strike, since the light has not reached her. At a later time, Fred has moved yet farther to the right, and Marie receives the two light pulses at the same instant. Marie measures off the distance between the scorch marks on the ground, finds herself to be at the midpoint and concludes that the two events were "simultaneous." Fred, who has already observed the light pulse from the right, will eventually receive the pulse from the left. He measures the distance to the two scorch marks on the train and concludes he was at the midpoint between the strikes but since Fred did not receive the two pulses coincidentally, he concludes the two events were not simultaneous."

"Beware the temptation to use your common sense on this one! Common sense would say that the forward speed of the train caused the light from the front of the train to speed up. But Einstein's second postulate says this isn't so: light always travels at the same speed. Common sense would also tell us that it *really did* happen simultaneously and that Marie, who is standing on the ground, should know since she wasn't moving. But Einstein's first postulate says that isn't right because uniform motion is not detectable or definable. The person standing on the ground, remember, is also moving at high speeds with the earth. The fact is that the lightning strike was simultaneous to Marie but not to Fred. It's all relative."

"And this is the basis for the rest of the theory?"

"That's right. These two postulates, the idea of simultaneity and the mass – energy exchange principle are what caused all the interesting things we saw here today."

"Thank you for joining us. That wraps it up for us here at CERN. This is John Cockcroft of Nuclear Physics Radio signing off. Good day."

Hannah had to admit that she was starting to find this crazy theory interesting. She opened the assignment file and read through the questions, hoping she would be able to answer them.

Footnote

[1] The physics teacher's quote at the beginning of each of the four versions is from Krauss, L. M. (1993). *Fear of physics: A guide for the perplexed*. (pp. 119-120). New York, NY: BasicBooks.

Table A1

Differences found in Abstract and Concrete Narratives

Abstract	Concrete
An experiment while moving and maintaining a constant speed	An experiment on a train that was maintaining 120 mph
As if you were standing motionless	As if you were standing next to the tracks
Going through space	Flying through space
Think of a time when you weren't sure if you were moving or if the objects around you were moving	Think of riding in an elevator
One frame of reference	Sally's frame of reference
Any other frame of reference	Jenny or Ben's frame of reference
Somewhere watching a wave moving away from you	In a speedboat on Lake Powell
It is quite possible for someone or something to pass it	You want to pass it up so you accelerate and quickly pass the wave
No matter how fast you went	Even if you had super jet propulsion that could get you almost to the speed of light
A stationary observer in a different location	The kid in the inner tube near the shore
Someone passes you	A red sports car passes you
The car	The sports car
M	Marie

Table A1 (continued)

Differences found in Abstract and Concrete Narratives

Abstract	Concrete
F	Fred
Positioned	Standing
When the two frames of references are lined up	When Fred and Marie are exactly across from each other
Become	Grow
Limit	Speed limit
When you heat something	When you warm tortillas in the oven
Pushing something the weighs very little and something very heavy	Pushing a wooden toy car and a stretch limousine
Constricted	Squished
Much larger objects	A cruise ship
An object	Your large beautifully wrapped Christmas present
Moving at everyday speeds	Running, riding a bike or flying in an airplane
People	Little grandmas
People on earth	Their friends on earth
Travelers’ space ship	Grandmas’ space ship
Traveling	Driving

Appendix B: Pretest

The following four questions will test your knowledge of Einstein's Special Theory of Relativity. Please answer each question the best you can. **If you do not know an answer, don't guess.** Just go on to the next question.

1. Explain what is meant by "mass increase".
2. Explain what is meant by "length contraction".
3. Explain what is meant by "time dilation".
4. Describe the universal relationship between mass and energy.

For each of the following statements, please indicate how true it is for you, using the following scale:

1	2	3	4	5	6	7
not at all true			somewhat true			very true

1. I will try very hard to learn about Einstein's Special Theory of Relativity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

2. I believe that learning about Einstein's Special Theory of Relativity could be of some value to me.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

3. I think that learning about Einstein's Special Theory of Relativity is useful.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

4. I don't feel nervous at all about learning this.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

5. Learning about Einstein's Special Theory of Relativity will not hold my attention at all.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

6. I feel very tense thinking about doing this activity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

7. Learning about Einstein's Special Theory of Relativity will be fun to do.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

8. I think learning about Einstein's Special Theory of Relativity is important.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

9. I think learning about Einstein's Special Theory of Relativity will be boring.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

10. I think reading this story about Einstein's Special Theory of Relativity will be quite enjoyable.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

11. I won't try very hard to learn about Einstein's Special Theory of Relativity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

12. It is important to me to learn about Einstein's Special Theory of Relativity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

13. I won't put much energy into learning about Einstein's Special Theory of Relativity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

14. I am very relaxed in learning about Einstein's Special Theory of Relativity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

15. I feel pressured to learn about Einstein's Special Theory of Relativity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

16. I think learning about Einstein's Special Theory of Relativity is an important activity.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

On the following page you will begin reading a story about Einstein's Special Theory of Relativity.

Read through the story ONCE and then proceed to the questions that follow.

Appendix C: Posttest

Answer each of the following questions to the best of your knowledge. Please ***do not*** look back at the story.

1. When you are in a spacecraft going almost the speed of light, are your shoes heavier or lighter or the same as usual when measured by someone outside the spacecraft?
    a. Lighter
    b. Heavier
    c. The same as usual

2. Explain what is meant by "mass increase" in Einstein's theory.

3. A friend tells you that what Einstein's equation $E=mc^2$ means that if you put more energy into a system, it will have more mass. Do you agree or disagree?
    a. Agree
    b. Disagree

4. You have two marbles that are the same size and density at room temperature. You heat one up and measure them again. Which weighs more?
    a. the hot marble
    b. the cold marble

5. If you travel in a small, lightweight spacecraft, can you catch up with a light beam?
    a. Yes
    b. No

6. A car is coming toward you when it is dark. The headlights are pointing right at you. Is the light coming at you at the usual speed of light or faster?
    a. The usual speed of light
    b. Faster than the usual speed of light.

7. Explain what is meant by "time dilation".

8. A friend tells you that he heard that for someone moving away from a clock on a light beam, the clock would appear to stop. He heard you say that you were taking physics and asks you if it's true. What do you tell him?
    a. Yes, the clock would appear to stop to someone riding away from it on a light beam.
    b. No, the clock would appear to run normally even if you were riding a light beam away from it.

9. You take a 12-inch ruler on a spacecraft trip to Jupiter at nearly the speed of light. Someone in the control room claims that they measure the ruler to be only six inches long. If you look at it, how long will you find it to be?
    a. 6 inches
    b. 12 inches
    c. 18 inches

10. Explain what is meant by "length contraction".

11. Your friend tells you that an astronaut observes all objects around (pencil, seat, instruments, etc…) to become shorter as his spaceship goes nearer the speed of light. Do you agree or disagree?
    a. Agree
    b. Disagree

12. Two of your friends are debating a physics question. Jessica says that she can get the same results doing an experiment in her basement that someone flying in a supersonic jet can get, as long as their speed was constant. Samantha says that there is no way this is true because the lab in the jet is moving. According to Einstein, who is right?
    a. Jessica
    b. Samantha

13. Suppose you are an astronaut traveling to Jupiter near the speed of light when lightning strikes both the spacecraft's nose and tail at the same time according to the control room back on earth. Do *you* think the strikes were simultaneous?
    a. Yes
    b. No

Questions 14 and 15: Read the situation below and then answer the following questions as they relate to it.

Somehow a constant force is exerted on an object at rest. The force remains the same in both magnitude and direction. It is the only force acting on the object and it is maintained for a very long time.

14. What happens to the mass of the object as it approaches the speed of light?
    a. It decreases.
    b. It increases.
    c. It stays the same.

15. What happens to the energy being supplied to the object as it approaches the speed of light?
    a. It makes the object more massive.
    b. It pushes the object to the speed of light.
    c. Nothing, an object going that fast no longer needs energy.

[The retention test was identical to the above with two additional questions:
** Have you read or studied anything on Einstein's Special Theory of Relativity since last week? If yes, please explain what you have read.

** Have you explained or discussed the concepts of Einstein's Special Theory of Relativity with anyone since last week? If yes, please list the concepts discussed.]

Appendix D: Concrete Word Test

The purpose of this test is to discover which of the following words or phrases set up **clearer, stronger pictures in your mind**. Please rate the following words or phrases on the scale that follows. *Work quickly, using your first impression as your guide.*

1. **pushing a wooden toy car and a stretch limousine**

very abstract, hard for me to form mental images of this	1	2	3	4	5	6	7	very concrete, easy for me to form mental images of this

2. **Jenny or Ben's (frame of reference)**

very abstract, hard for me to form mental images of this	1	2	3	4	5	6	7	very concrete, easy for me to form mental images of this

3. **a time when you weren't sure if you were moving**

very abstract, hard for me to form mental images of this	1	2	3	4	5	6	7	very concrete, easy for me to form mental images of this

4. **traveling … toward the observers**

very abstract, hard for me to form mental images of this	1	2	3	4	5	6	7	very concrete, easy for me to form mental images of this

5. **riding in an elevator**

very abstract, hard for me to form mental images of this	1	2	3	4	5	6	7	very concrete, easy for me to form mental images of this

6. **a speedboat on Lake Powell**

very abstract, hard for me to form mental images of this	1	2	3	4	5	6	7	very concrete, easy for me to form mental images of this

7. even if you had super jet propulsion that could get you almost to the speed of light

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

8. no matter how fast you went

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

9. a stationary observer in a different location

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

10. anyone's (frame of reference)

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

11. the kid in the inner tube near the shore

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

12. someone (passes you)

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

13. somewhere

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

14. a red sports car (passes you)

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

15. traveling… toward Fred and Marie

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

16. (simultaneous to) Marie but not Fred

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

17. going through space

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

18. a cruise ship

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

19. running, riding a bike or flying in an airplane

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

20. constricted

1 2 3 4 5 6 7

very abstract, hard for me to form mental images of this — very concrete, easy for me to form mental images of this

21. moving at everyday speeds

1 2 3 4 5 6 7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

22. when Fred and Marie are exactly across from each other

1 2 3 4 5 6 7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

23. your large, beautifully wrapped Christmas present

1 2 3 4 5 6 7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

24. (simultaneous to) M but not F

1 2 3 4 5 6 7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

25. an object

1 2 3 4 5 6 7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

26. flying through space

1 2 3 4 5 6 7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

27. little grandmas

1 2 3 4 5 6 7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

28. heat something

1	2	3	4	5	6	7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

29. when the two frames of references are lined up

1	2	3	4	5	6	7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

30. warm tortillas in the oven

1	2	3	4	5	6	7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

31. much larger objects

1	2	3	4	5	6	7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

32. pushing something that weighs very little and something heavy

1	2	3	4	5	6	7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

33. squished

1	2	3	4	5	6	7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this

34. people

1	2	3	4	5	6	7

very abstract,
hard for me to form mental images
of this

very concrete,
easy for me to form mental images
of this