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How Learning About Scientists' Struggles Influences Students' Interest and Learning in Physics

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How does learning about scientists' struggles during their scientific knowledge building affect students' science learning? Two hundred and seventy-one high school students were randomly assigned to 1 of 3 conditions: (a) the struggle-oriented background information ($n = 90$) condition, which presented students with stories about 3 scientists' struggles in creating the content knowledge that the students were learning through online physics instructional units; (b) the achievement-oriented background information ($n = 88$) condition, in which students learned about these 3 scientists' lifetime achievements; and (c) a no background information ($n = 93$) condition, a control group in which students mainly learned information about the physics contents they were studying. Our measures assessed perceptions of scientists, interest in physics lessons, recall of science concepts, and physics problem solving. We found that the achievement-oriented background information had negative effects on students' perceptions of scientists, producing no effects on students' interest in physics lessons, recall of science concepts, or their solving of both textbook-based and complex problems. In contrast, the struggle-oriented background information helped students create perceptions of scientists as hardworking individuals who struggled to make scientific progress. In addition, it also increased students' interest in science, increased their delayed recall of the key science concepts, and improved their abilities to solve complex problems. The important message that learning about scientists' struggles sends is that even great scientists work hard. Providing an opportunity for students to relate scientists to their knowledge-building activities has important implications for science learning and instruction.

Keywords: scientists' struggles, personal background information, science learning, learning interest, perceptions of scientists

A major goal of this study is to explore how learning about scientists' personal backgrounds, particularly how scientists struggle during their scientific knowledge building, affects students' interest and learning in science. This motivational approach is different from many efforts to increase students' motivation to learn by creating instructional materials (e.g., textbooks or computer-based instructional materials) that are more interesting, fun, or engaging for students. For instance, many science textbooks incorporate stimulating illustrations or visual images in order to motivate students to learn the content (Hannus & Hyönä, 1999; Mayer, Bove, Bryman, Mars, & Tapangco, 1996). Another common approach to increase motivation is to promote students' interest in science by enhancing the overall readability of the texts (Otero, Leon, & Graesser, 2002). These efforts are undoubtedly important for science education, as textbooks constitute a major source of science learning (Kuhn, 1970; Memory & Uhlhorn, 1991); it is more difficult to motivate students to study uninteresting science texts (Holliday, 2002). However, despite these considerable efforts, science textbooks are still perceived as serious and unmotivating (Chambliss, 2002; Chambliss & Calfee, 1998).

In addition to external factors such as how engaging the material is, many internal factors influence students' motivation and learning. For example, research by Dweck and colleagues (Dweck, 1999, 2007; Dweck & Leggett, 1988; Dweck & Sorich, 1999) suggested that individuals' beliefs about the nature of their ability and intelligence powerfully influence their success in learning. Those who believe that intelligence is a fixed entity (*entity theorists*) give up or withdraw quickly when facing challenging tasks. In contrast, people who believe that intelligence is malleable and can be increased incrementally with effort (*incremental theorists*) are more likely to hold learning goals in school. In turn, these students with an emphasis on developing understanding often engage in deeper and more self-regulated learning strategies, have higher intrinsic motivation, and perform better, particularly in the face of setbacks (Ames, 1992; Dweck & Leggett, 1988; Elliot, 1999; Pintrich, 2000; Robins & Pals, 2002). Individuals who

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believe intelligence is malleable are also more likely to see effort as an important factor in achieving success, whereas individuals who believe intelligence is fixed are more likely to see effort as a sign of low ability and lack of intelligence. Blackwell, Trzesniewski, and Dweck (2007) examined whether helping students see that intelligence is malleable affected students' motivation and academic performance in school. For instance, they taught students that the brain is like a muscle—the more students exercise it, the stronger it becomes. Every time they try hard and learn something new, their brains form new connections that, over time, make them smarter. They also learned that intellectual development is not the natural unfolding of innate intelligence but rather the formation of new connections brought about through effort and learning (Blackwell et al., 2007). An important message that underlies this instructional intervention is that we can develop our own intelligence through hard work and learning. The intervention has helped students develop productive theories of intelligence and enhanced students' motivation and academic achievement.

Another way to use effort beliefs to motivate students' learning, particularly in the area of science education, is to use stories that illustrate scientists' struggles toward new discoveries. Many science educators have suggested that a scientist's personal narratives, anecdotes, self-reflections, or life stories are valuable resources to inspire science learning (Eshach, 2009; Haven, 2007; Klopfer, 1966; Martin & Brouwer, 1991, 1993; McKinney & Michalovic, 2004; Milne, 1998; Rowcliffe, 2004; Solomon, 2002; Stinner, 1995; Stinner & Williams, 1993). As noted by McKinney and Michalovic (2004), "by using a wide variety of biographies and histories teachers can stimulate student interest, provide role models for all students, and generally give a more complete picture of the nature of scientific work" (p. 46). For instance, a project called History of Science Cases was implemented (see Conant, 1957) in which historical stories about scientists were included in science textbooks. About 10% of the secondary school students in the United States participated in this experimental study. Although they did not achieve statistically significantly better grades than the students in the control groups, their motivation to study science-related issues became higher (Klopfer, 1966). More recently, in a literature review of more than 350 studies from 15 separate fields of science, Haven (2007) concluded that stories are "an effective and efficient vehicle for teaching, for motivating, and for general communication of factual information, concepts, and tacit information" (p. 4). Cognitive studies also suggest that people remember stories and information in stories better and longer than the same information presented in any other narrative form (Mandler, 1984; Mandler & Johnson, 1977).

However, other researchers have argued that stories may be harmful for aspects of learning, as they may become distractions from learning the subject matter. For example, two studies conducted by Garner, Alexander, Gillingham, Kulikowich, and Brown (1991) investigated how the placement of interesting detail in a text about a physicist and his scientific work negatively affected recall of the physics content. They found that students' attention was diverted from important concepts within the text to interesting and irrelevant details in the stories (for more examples, see Garner, Gillingham, & White, 1989; Harp & Mayer, 1998).

Research also indicates that interesting science stories covered in public media, such as newspapers and movies, tend to reinforce existing stereotypical images of science and scientists. For example, Weingart, Muhl, and Pansegrau (2003) analyzed the depictions of scientists in more than 200 movies. They found that scientific inquiry was alarmingly portrayed as the "modification of, and intervention into, the human body, the violation of human nature, and threats to human health by means of science," with images of scientists as "pursuing the quest for new knowledge in secrecy, outside the controls of academic institutions and peers" (Weingart et al., 2003, p. 279). Thus, some types of science stories may be detrimental to the perception of science, thereby discouraging students from interest in science.

In the present study, we investigate the potential value of a particular type of story consisting of personal background information (see Lin & Bransford, 2010) about scientists' experiences, efforts, and struggles to make important scientific discoveries. Students often do not fully recognize that scientific knowledge was created by people; if they do know, they think that only unusually smart people can "do" science (Carey, Evans, Honda, Jay, & Unger, 1989; Dweck, 2010; Sandoval & Morrison, 2003; Schoenfeld, 1988). Many students do not believe that scientists are ordinary people who have limitations, need to work hard, and must go through struggles in order to discover new phenomena or invent new theories (Roth, van Eijck, Hsu, Marshall, & Mazumder, 2009). This misconception about science emphasizes only that knowledge exists rather than focusing on the historical and personal processes through which the knowledge was created. A review of research in this area led us to hypothesize that understanding the difficulties and struggles that scientists went through in creating scientific theories may increase students' interest and understanding of science content (Hong & Lin, 2008; Lin & Bransford, 2010; Lin, Schwartz, & Bransford, 2007).

The primary focus of this study is to explore how learning about scientists' struggles and work experiences within physics, as presented in a story format, affects Taiwanese students' (231 males and 40 females) interest and learning in science. First, we discuss why we believe that personal background information about scientists would enhance students' learning of science content. Next, we describe the types of personal background information investigated in the present study. Finally, we report our findings and discuss their implications for science education and future research.

Why Is Personal Background Information Useful?

According to situated learning theory, learning should not be viewed as simply the transmission of abstract and decontextualized knowledge but as a sociocultural process whereby knowledge is co-constructed in context (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1989). Personal background information about scientists' struggles is a kind of contextual knowledge, which is acquired through a type of knowing that Broudy (1977) referred to as *contextual knowing* or *knowing with*. This type of knowing is different from *knowing that* and *knowing how* (Ryle, 1949). Conventional textbook-based science learning is reflexive of these two latter types of knowing. Broudy argued that "knowing with" is another equally important type of knowing that can complement the other two types of knowing but is often neglected in formal education. In particular, science instruction often omits personal and historical context concerning the development of scientific theories (Dagher & Ford, 2005; Klopfer, 1969). In this study, we examine the effects of science learning materials that explicitly reveal the contexts (e.g., scientists' personal backgrounds) within which the content knowledge was created. We argue that exposure to scientists' struggles in making their scientific discoveries may aid science learning in at least four ways: (a) by helping students organize knowledge effectively to support recall; (b) by enhancing both the social and humanistic presence of scientists; (c) by increasing students' interest in learning science; and (d) by offering students firsthand experiences that provide insights into scientists' thinking and promote understanding of scientific theory development.

First, helping students connect to the people who produced the information they are studying could have profound effects on students' ability to mentally organize their knowledge. Mandler (1984) argued that a story or narrative provides an organizing structure (i.e., context) and therefore fosters the creation of new experiences and knowledge, or affords students the opportunity to create meaning. As Wells (1986) noted, "constructing stories in the mind—or *storying*, as it has been called—is one of the most fundamental means of making meaning . . . as such, it is an activity that pervades all aspects of learning" (p. 214, emphasis in original).

Experts in other areas (e.g., educational researchers) also organize their knowledge around the people who produced the knowledge, not simply around isolated facts and topics. Loftus and Loftus (1974) found that background information about psychologists played an important role in college students' foundational knowledge of psychology when measuring successful recall of psychologists' names and their research findings. Even background information about the authors of articles helps us understand their work in a way that differs from exposure to the same articles without some level of background information (Nolen, 1995).

Research shows that humans can possess exceptionally deep biographic knowledge about famous people such as historic authors, artists, poets, or scientists (Hodges & Graham, 1998; Mackenzie Ross & Hodges, 1997); even very young children use knowledge of others to understand the world (Bretherton, McNew, & Beeghly-Smith, 1981). Organizing knowledge around people, when in combination with facts and abstract concepts, provides multiple retrieval routes to information, which may facilitate better access to relevant knowledge (Mandler, 1984). However, little is known about how background information, particularly information about how scientists struggle, influences students' learning in science.

Second, integrating background information of scientists within the science curriculum may increase the social presence of scientists in students' minds. Short, Williams, and Christie (1976) defined *social presence* as the "salience of the other person in the interaction and the consequent salience of the interpersonal relationships" (p. 65). Knowing that scientists struggle and experience difficulties with experiments makes them real and approachable. This feeling of closeness to scientists may inspire people to emulate scientists' learning or problem-solving practices (Gunawardena, 1995).

Similarly, when students know background information about their instructors, the instructors often have higher social presence among students. The instructors are thus often perceived as more real, positive, and effective, which inspires more positive emotions among students and increases course ratings as well (Gunawardena, 1995; Lin & Bransford, 2010). Such positive relationships may motivate students to invest more effort to develop a deep understanding of the content knowledge they are learning (Christophel, 1990; Hackman & Walker, 1990). Thus, personal background information may create a strong social presence and improve learning.

Third, integrating personal background information about scientists may increase interest in science learning. There are in general two kinds of interest—*personal interest* and *situational interest* (Hidi, 2006; Hidi & Anderson, 1992). Personal interest means interest that students bring to the learning environment. For example, some students come to a science classroom already interested in the subject matter, whereas others do not (Mitchell, 1993). In contrast, situational interest is acquired when individuals participate in the learning environment. For example, some learning environments are more motivating than others. Both types of interest are important for enhancing science learning, but personal interest usually develops slowly; therefore, creating more interesting science learning environments becomes very important, especially for students with low personal interest in science. Schraw, Flowerday, and Lehman (2001) argued that providing the contextual information needed to fully understand a learning topic increases learning interest. Empirical findings also suggest that interest, as a unique motivational variable, tends to generate positive effects on the processes and outcomes of learning (Hidi, 2006; Krapp, 2007; Silvia, 2006). Humans, by nature, are highly interested in hearing stories about other humans (Dewey, 1913). Hence, personal background information should help increase students' interest (in particular, situational interest) in science learning.

Finally, background information can also improve one's overall motivation to learn and solve problems (Paxton, 1997). It was found that simply revealing the identity of the author of a statistics book and providing information about his personality and attitudes toward statistics enhanced students' interest in reading the book and understanding the content (Nolen, 1995). Similarly, Palincsar and Magnusson (2001) found that young children were motivated to learn science by the introduction of a fictitious scientist who shared her personal investigations throughout the text. Lin and Bransford (2010) found that increasing students' knowledge about their foreign professor's personal background strongly increased students' motivation to seek out more information and to generate more thoughtful solutions for a given problem.

The Present Study

In the present study, we examined whether students' physics learning would improve when we used two particular kinds of scientist background information: (a) achievement-oriented background information, which described three scientists' (i.e., Galileo, Newton, and Einstein) lifetime achievements, and (b) struggle-oriented background information, which presented stories about the three scientists' struggles in developing theories. With an underlying assumption that the two types of personal background information represent two different types of contextual knowledge with different instructional value, we designed the present study to answer the following specific questions:

1. How do achievement-oriented background information and struggle-oriented background information affect students' overall

perceptions of scientists in general, as well as images of the three scientists?

2. How do achievement-oriented background information and struggle-oriented background information affect students' overall interest in the physics lessons in this study—especially for students with low personal interest in science?

3. How do achievement-oriented background information and struggle-oriented background information affect students' science learning in terms of (a) their recall of the key scientific terms presented in this study and (b) their ability to solve both textbook-based problems (problems that require just one kind of formula or one particular scientist's theory) and complex problems (problems that require application of multiple formulas and theories)?

Research Design, Materials, and Procedure

Participants and Study Design

A total of 271 tenth-grade students (231 males and 40 females) in a public high school in Taiwan participated in the study. Their ages ranged from 16 to 18, and most of them came from low- to middle-income families. Moreover, they were low-achieving students. Each year, only about 30% of students in this school passed the national college entrance exam and continued their education at national universities (the school's Office of the Registrar, personal communication, August 26, 2009). The overwhelming majority of studies on how to improve low-achieving students' learning of mathematics and science published in U.S. journals focus on Western countries. Understanding how to improve the science learning of low-achieving Asian students is equally important.

Additionally, as background information, previous research indicates that Taiwanese students' cultural perceptions of science and scientists are strongly influenced by science textbooks (She, 1995), and the design of science curricula and textbooks in Taiwan has closely followed the Western science tradition and standard (Chang, 2005).

Students were randomly assigned to one of three conditions: (a) an achievement-oriented background information (BI) condition ($n = 90$), (b) a struggle-oriented BI condition ($n = 88$), and (c) a no BI condition ($n = 93$). Students in the achievement-oriented BI condition studied the three scientists' (i.e., Galileo, Newton, and Einstein) major successes and achievements in life. Students in the struggle-oriented BI group studied the same three scientists but focused on their struggles during their scientific discoveries (see the Instructional Materials section below for examples of these stories). The no BI condition represented a conventional science curriculum, with learning materials organized mainly around content knowledge and superficial background information (i.e., the introduction of scientists in science textbooks chiefly by their names and dated discoveries).

Instructional Materials

Physics lessons. There were three computer-based physics lessons (e.g., see http://www3.nccu.edu.tw/~hyhong/website/SPK.htm). The first two lessons were adapted from a widely used regional science textbook designed for high school students (Nan, 2002). All students learned some basics about Galileo and Newton's theories when they were in middle school. The third lesson was completely new to students and was adapted from college physics textbooks (Holton, Rutherford, & Watson, 1970; Nan, 2002; Sears, Zemansky, & Young, 1989; Serway, 1990). The science content within all three lessons focused around several physics laws or theories, as well as real-life problems that can be solved using these laws/theories. Two science teachers who have taught the above science units for more than 10 years validated the accuracy of the science content included. Lesson 1 focused on Galileo's law of free fall and law of inertia. For example, the law of free fall was introduced to students using a mathematics formula, which explained that the distance of a fall will be proportional to the square of the time of the fall: $d = (1/2)gt^2$, where g is the gravitational acceleration constant. Lesson 2 focused on Newton's three laws of motion and law of gravity. For instance, Newton's third law of motion explains that whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. Lesson 3 explored Einstein's theory of relativity in relation to mass–energy equivalence and the time–space issue. For instance, Einstein's famous equation, $E = mc^2$, illustrates that E represents energy, m represents mass, and c represents the speed of light (3×10^8 m/s). The equation implies that even very small amounts of mass, such as an atom, can hold extremely large amounts of energy. The average number of words for each lesson was 1,075 (*SD* = 170.2), and the time for studying a lesson in a self-paced manner was about 12 min.

Achievement-oriented and struggle-oriented BI. The achievement-oriented and struggle-oriented BI about each scientist were adopted from various biographic or autobiographic sources (Einstein, 1956; Haven, 1996, 1997; Machamer, 1998; Schilpp, 1951; White, 1997). Both types of learning materials were similar in length. All learning materials employed in this study were validated by the same two science teachers mentioned above.

The selection criteria for achievement-oriented BI consisted of important scientific discoveries, breakthroughs, and historical events that represented a scientist's major achievements throughout life. Below are three examples of achievement-oriented BI about each scientist from this study:

> 1. In 1583, Galileo formulated the idea of an equal duration of the pendulum swing while watching the oscillations of a lamp in the cathedral of Pisa. . .; in 1597, [Galileo] invents a geometric and military compass. . .; in 1610, Galileo discovers four moons orbiting Jupiter.
>
> 2. Newton (1643–1727) was born in Woolsthorpe, Lincolnshire, England. . .; in 1665, Newton invents his calculus. . .; in 1672, Newton is elected a member of the Royal Society.
>
> 3. Einstein's special theory of relativity was published in 1905. . .; in 1907, Einstein begins applying the laws of gravity to his theory of relativity; in 1909, Einstein is appointed extraordinary professor of theoretical physics at Zurich University.

All of the achievements in a scientist's life were organized and presented chronologically. For a full example see Appendix A, where the complete achievement-oriented BI about Galileo is provided.

As defined by the *Oxford Dictionary*, to *struggle* means to "strive to achieve or attain something in the face of difficulty or resistance" ("Struggle," n.d.). Based on this definition, the main criteria for selecting struggle-oriented materials consisted of relevant information about a scientist's intellectual, personal, and social struggles that led to important inventions and discoveries. Below are three examples to illustrate struggle-oriented BI about the three scientists from this study:

> 1. According to Aristotle, the speed of a falling body is proportional to its weight. . . . However, this was not what Galileo observed during a hailstorm, in which he noticed that both large and small hailstones seemed to fall at the same speed and hit the ground at the same time. . . . This inspired Galileo to disprove Aristotle's theory.
>
> 2. During parts of the years 1665 and 1666 . . . [Newton] thought out the fundamental principles of his theory of gravitation. . . . While the famous fable suggests that Newton was inspired by seeing an apple drop from a tree, it was actually his hard work and inquisitive nature that led to his formulation of a gravitational theory. As he said, "I keep the subject constantly before me, till the first dawnings open slowly, by little and little, into the full and clear light."
>
> 3. Einstein's general theory of relativity did not completely satisfy him because it did not include electromagnetism. Beginning in the late 1920s, he tried to combine electromagnetic and gravitational phenomena in a single theory, called a unified field theory. Einstein failed to establish a unified field theory, though he spent the last 25 years of his life working on it.

For a full example see Appendix A, where the complete struggle-oriented BI about Galileo is provided.

Design of an online learning environment. A complementary goal in this study was to design an informal online learning environment for students to explore science at their own pace and in their spare time. Therefore, all of the self-study activities took place in an online learning environment. One main reason for this design was because the participating school was equipped with high-speed Internet access but lacked meaningful online learning resources. The informal online learning environment was designed to serve as a resource to supplement the school's formal science instruction. The online lessons consisted of the following two components: (a) science content, consisting of the three physics lessons described above, and (b) struggle- and achievement-oriented stories about the scientists, including the images of the three scientists and their personal backgrounds. Since the purpose was to investigate the effects of struggle- versus achievement-oriented BI on learning and not the effects of the technological features, we purposefully excluded any unnecessary multimedia designs to avoid possible confounding variables. For instance, adding animation would make it difficult to then determine if students' interest in science was increased or decreased due to struggle-oriented BI, achievement-oriented BI, or animation.

Measures

This study employed the following surveys and tests as measures (see Table 1). In addition to the measures, a demographic survey was administered at the beginning of the study. Details about each instrument and the implementation procedure are described below.

Images of Scientists Survey. This survey measured students' perceived images of scientists in general. It was adapted from Krajkovich's (1978; Krajkovich & Smith, 1982) Image of Science and Scientists Scale. Examples of items used to describe scientists include "is intelligent," "has little social life," and "works for the benefit of humankind." The original Image of Science and Scientists Scale contains 48 items and uses a 6-point Likert-type response format. Since the main purpose of the present study was to investigate the image of scientists, items relevant to the image of science were dropped. As a result, 18 items remained. In a pilot test involving 116 tenth graders in the same school, the Cronbach alpha reliability was calculated to be .74. Further, a factor analysis revealed that construct validity was supported for the instrument, with the percentage of explained variance calculated to be 64.42%. To answer the first research question, a repeated-measures analysis of variance (ANOVA) was employed to assess differences in terms of students' perceived images of scientists among groups.

Images of Three Scientists Survey. This survey measured how students perceived the three specific scientists (Galileo, Newton, and Einstein) they learned about during online physics lessons. This survey was designed by the authors and consisted of nine open-ended questions. All questions asked participants to describe their perceptions and mental images of the scientists. An example question is "Could you describe three things about Einstein that impress you the most?"

An initial qualitative analysis based on an open-coding procedure (Chi, 1997; Strauss & Corbin, 1990) was employed. Three major kinds of images emerged: achievement-oriented, ability-oriented, and struggle-oriented. The achievement-oriented images mainly depicted scientists' successes and discoveries. For example, some students mentioned "Galileo invented the thermometer" or "Einstein received Nobel Prize." The ability-oriented images mainly emphasized scientists' personal qualities or innate abilities. For instance, some students mentioned "Newton is a genius." The

Table 1
Measures Employed in the Study

Measure	Description	Implementation	Time required
Images of Scientists Survey	18 Likert-scaled questions	1. Preassessment: in the beginning of Week 1	5 min
		2. Postassessment: at the end of Week 2	5 min
Images of Three Scientists Survey[a]	9 open-ended questions	At the end of Week 1	10 min
Interest in Physics Lesson Survey	14 Likert-scaled questions	At the end of Week 1	3 min
Recall Test	60 response items	1. Immediate recall: At the end of Week 1	5 min
	Same items (different order)	2. Delayed recall: At the end of Week 2	5 min
Textbook-Based Problem-Solving Test	30 multiple-choice questions	At the end of Week 1	20 min
Complex Problem-Solving Test	7 open-ended questions	At the end of Week 2	40 min

[a] The three scientists were Galileo Galilei, Isaac Newton, and Albert Einstein.

struggle-oriented images focused on scientists' investigative efforts or their experimental trials and errors during the process of scientific invention. For example, some students described Galileo as someone who "never gave up on his experiments." These three kinds of coding schemes of the images were then employed to tally the image responses to each of the nine questions for every student. The score for each of the three kinds of images ranged from one to nine. Two raters independently coded each response and the interrater agreement was 96%. A multivariate analysis of variance (MANOVA) was employed, using the three different image scores as combined dependent measures, to assess differences in perceived images of the three scientists among groups.

Interest in Physics Lesson Survey. This survey measured the extent to which students found a given physics lesson interesting. The survey was developed by the authors and involved fourteen 5-point Likert-type prompts (see Appendix B). Item 1 measured the interest in the general topics covered in the lessons (Hidi & McLaren, 1991). Item 2 measured students' interest level in the overall content and text of the lessons (Kintsch, 1980). Items 3 and 4 measured cognitive interest (i.e., a text may be interesting because of the intricate pattern of events that is described or because of the way it is told) in the content of a given lesson (Hidi, 2001; Hidi & Baird, 1988; Mitchell, 1993). Items 5 and 6 measured students' interest in the specific scientific laws and examples discussed in the lessons. Items 7 and 8 asked participants if they would recommend the lesson to their friends and other students and whether they would like to study similar lessons (Hidi, 2001). Items 9 to 14 focused on students' interests specifically related to the scientist introduced in a given lesson (Dewey, 1913; Martin & Brouwer, 1991, 1993; Stinner, 1995; Stinner & Williams, 1993).

To collect initial evidence for the validity of this instrument, we performed a pilot test on the same 116 tenth-grade students mentioned above. A factor analysis was conducted. Two factors with eigenvalues greater than 1 were extracted, and construct validity was supported for the instrument, with the percentage of explained variance calculated to be 63.92%; in addition, the Cronbach alpha reliability estimate was .93. For statistical analysis, a two-way ANOVA—three types of treatments by two levels of personal interest (see below for detail about this personal interest measure)—was conducted to assess students' interest in the physics lessons.

Recall Test. This multiple-choice test measured the extent to which students remembered the key terms mentioned in the three physics lessons. It consisted of 60 response items, 20 items from each lesson. Each response item was represented by a key term/concept (e.g., "$E = mc^2$," "kinetic," and "space–time"). Each key term was randomly selected from the three lessons. Half were slightly changed to become plausible distracters (false key terms). For example, *acceleration* was changed to *deceleration*. A correct item earned 1 point; the possible maximum score was 60. The Cronbach alpha reliability estimate was .70. An integrative 2 × 3 (recall by treatments) repeated-measures ANOVA was performed to test the effects of background information on immediate and delayed recall.

Textbook-Based Problem-Solving Test. This test measured students' ability to solve problems relating to scientific laws or theories learned with relatively well-defined answers. The test consisted of 30 multiple-choice questions, 10 from each lesson. For example, based on the Newton physics lesson, a question asked,

> In which of the following situations does Newton's first law of motion not apply?
>
> (a) One blows off the dust on the table.
>
> (b) A passenger leans forward when the bus suddenly stops.
>
> (c) When a cannon is fired, it moves backward a little.
>
> (d) One cannot stop running immediately when finishing a 100-meter race.

All the questions were adapted from existing textbooks (Nan, 2002). Students earned 1 point for each correct answer to a question. The test was content validated by the two science teachers. The Cronbach alpha reliability estimates were .81. A MANOVA was conducted to compare the three groups, using the Textbook-Based Problem-Solving Test and the Complex Problem-Solving Test (see below) as multiple dependent variables.

Complex Problem-Solving Test. This test measured students' ability to identify the conceptual gaps and relatedness among the scientific laws/theories covered in all the lessons. The test contained seven open-ended questions (see Appendix C). As the questions were all open ended, scoring rubrics were developed. Both the questions and rubrics were initially developed and revised based on answers from a pilot study of 34 eleventh graders from a different high school who had similar academic backgrounds. The pilot test revealed two important findings: that students in general have difficulties seeing the relationships between different scientific theories or laws and that providing relevant contextual information and reflection time was helpful for students to recognize these relationships. The questions and rubrics were then further revised based on suggestions from a panel consisting of two tenth-grade students from a top senior high school in Taiwan and three natural scientists. Table 2 shows the rubrics developed and examples of answers. Depending on the quality of an answer, 0, 1, or 2 points were assigned to each question. For instance, 0 points were given when students did not answer the question or gave incomplete, unclear, or irrelevant answers. One point (or 2 points) was given when students were able to elaborate one relationship (or more than one relationship) between scientific laws, such as identifying when the same variable (or more than one variable) was used in both scientific laws. To compute interrater reliability, two raters independently scored all students' answers based on the developed rubrics, and the result was calculated to be .96. In addition, to ensure validity of all learning measures (including the Recall Tests, the Textbook-Based Problem-Solving Test, and the Complex Problem-Solving Test), we (a) identified all key concepts to be tested within the three sciences lessons; (b) developed a two-way specification table showing the percentage of coverage of each key concept tested within the physics lessons (see Table 3); (c) had two additional science teachers independently content validate the accuracy of all learning measures and evaluate whether each item in the learning measures was testing what it claimed to be testing (using a 5-point Likert scale in which 1 = *extremely disagree* and 5 = *extremely agree*), with the resulting validity coefficient computed to be .99; and (d) calculated criterion-related validity—using the same 116 tenth-grade stu-

Table 2
Rubric for Grading the Open-Ended Questions in the Complex Problem-Solving Test

Score	Criterion	Example
0 points	- Gives irrelevant answers.	- I am not familiar with these scientists.
	- Gives incomplete or unclear answers.	- There seems to be a relationship. But I don't know how to say it.
	- States no relationship.	- I think there is no relationship between the two laws.
	- Says don't know.	- I don't know.
	- Leaves blank.	
1 point	- States a mechanical/physical relationship between scientific laws.	- The law of conservation of mass and the law of conservation of energy are both related to the equation $E = mc^2$. - The law of free fall is a manifestation of Newton's law of gravity. - Newton's first law of motion is basically the same as Galileo's law of inertia.
	- States an epistemic/evolutionary relationship between scientific laws.	- Newton was inspired by Galileo's idea and came up with the three laws of motion. - Einstein modified Newtonian physics.
2 points	- Mentions more than two kinds of relationship at the same time.	- Einstein's special theory of relativity revised Newton's three laws of motion; a key factor is time. Newton thought time is absolute while Einstein proposed time is relative.

dents mentioned above—by relating these students' combined scores in the learning outcomes measures with their final-term science grades of the previous semester, with the resulting correlation being .280 ($p < .01$).

Demographic data. A demographic survey was developed to collect students' personal information (i.e., age, gender, and personal interest in science). Specifically regarding personal interest, a question was developed that asked students to self-report "whether or not they are personally interested in science." As a result, 129 students reported higher level personal interest and 142 students reported lower level personal interest. In a meta-analysis of 16 interest studies, Schiefele, Krapp, and Winteler (1992) concluded that, on average and across different subject areas, the level of interest accounts for about 10% of observed achievement variance. As a validity check on this item developed for capturing students' personal interest, we performed an ANOVA on students' science grades from the previous semester between the above two groups, which revealed a significant difference, $F(1, 269) = 9.11$, $p < .01$, $\eta^2 = .033$, observed power = .85, in that students with higher level personal interest in science had significantly better science grades ($M = 72.06$, $SD = 12.46$) than students with lower level personal interest in science ($M = 67.65$, $SD = 11.62$).

Moreover, the demographic survey was used to screen out students who had already been exposed to extensive biographic information about Galileo, Newton, and Einstein before the study.

Table 3
Two-Way Specification Table Showing Percentage of Coverage of Content Knowledge Tested in the Three Physics Lessons

Content	Recall Test	Textbook Problem-Solving Test	Complex Problem-Solving Test
Lesson 1			
Galileo's law of free fall	15 (25%)	6 (20%)	2.5 (17.9%)
Galileo's law of inertia	5 (8.3%)	4 (13.3%)	2.5 (17.9%)
Lesson 2			
Newton's 1st law of motion	6 (10%)	4 (13.3%)	0.83 (5.9%)
Newton's 2nd law of motion	4 (6.7%)	2 (6.7%)	0.83 (5.9%)
Newton's 3rd law of motion	5 (8.3%)	2 (6.7%)	0.83 (5.9%)
Newton's law of gravity	5 (8.3%)	2 (6.7%)	2.5 (17.9%)
Lesson 3			
Einstein's theory of relativity (about energy & mass)	12 (20%)	3 (10%)	3 (21.4%)
Einstein's theory of relativity (about time & space)	8 (13.3%)	7 (23.3%)	1 (7.1%)
Total score (% of content covered)	60 (100%)	30 (100%)	14 (100%)

Note. The learning outcome measures were developed for use with the tenth graders in the participating school and were developed in the Chinese language. The number in each cell refers to the score assigned in a given test, whereas the adjacent percentage of coverage is calculated by the score in each cell divided by the total score in a given test.

Table 4
Differences Among the Three Treatment Groups for All Measures Tested in the Study

	Group (A)										
	S-BI ($n = 88$)		A-BI ($n = 90$)		N-BI ($n = 93$)						
Measure[a]	*M*	*SD*	*M*	*SD*	*M*	*SD*	Source	*F*	η^2	Power	Scheffe test[b]
Image of scientists											
All scientists in general (B)							A × B	1.54	.011	.33	S-BI > N-BI***
Preassessment	4.30	0.43	4.17	0.55	4.01	0.57	A	10.23**	.071	.99	Pre > post***
Postassessment	4.24	0.46	3.99	0.55	3.92	0.56	B	13.32**	.047	.95	
Galileo, Newton, & Einstein											
Achievement oriented	3.06	2.22	5.06	2.46	3.75	2.44		16.22***	.108	.99	A-BI > S-BI*** A-BI > N-BI***
Ability oriented	0.07	0.25	0.43	1.67	0.24	0.60		2.78	.020	.55	
Process oriented	1.67	1.71	0.48	0.72	0.48	0.64		33.43***	.200	.99	S-BI > A-BI*** S-BI > N-BI***
Situational interest in science lessons							A × B	6.34**	.046	.90	Low: S-BI > N-BI**
Initial personal interest (B)							A	2.22	.016	.45	N-BI: high > low***
Higher level	3.47	0.47	3.34	0.56	3.65	0.55	B	29.70***	.101	.99	
	($n = 46$)		($n = 44$)		($n = 39$)						
Lower level	3.32	0.45	3.11	0.59	2.98	0.54					
	($n = 42$)		($n = 46$)		($n = 54$)						
Recall (B)							A × B	14.26***	.096	.99	Delayed: S-BI > N-BI***
Immediate	33.75	4.29	35.01	5.93	35.54	5.76	A	1.35	.010	.29	S-BI: delayed > immediate***
Delayed	39.08	5.76	36.92	6.36	35.14	6.01	B	25.65***	.087	.99	
Problem solving											
Textbook-based problem	14.83	4.42	15.21	4.10	14.48	5.22		0.57	.004	.14	
Complex problem	1.93	1.69	0.78	1.08	0.74	0.82		26.52***	.165	.99	S-BI > A-BI** S-BI > N-BI**

Note. S-BI = struggle-oriented background information; A-BI = achievement-oriented background information; N-BI = no background information (control group).
[a] All are dependent variables except for "personal interest," which is an independent variable. [b] The *p* value in this study was set at .01.
** $p < .01$. *** $p < .001$.

Students were ineligible if they met the following two criteria: (a) they reported having read all three scientists' biographies before and (b) their answers demonstrated extensive and accurate biographic knowledge on the open-ended questions. Eight students were disqualified based on the agreement of the same two science teachers mentioned above.

Procedure

To ensure consistency in the implementation of the study, the head of the Research Division at the participating school administered the study from beginning to end. The intervention lasted for 2 weeks. In Week 1, students completed the pretests and the three online lessons. During this week, the researcher first described the activities involved in the study. He then administered the pretests in the following sequence: the demographic survey followed by the Images of Scientists Survey. Students then studied the three physics lessons at their own pace in a computer lab. At the end of each lesson, the Interest in Physics Lesson Survey for each of the three lessons was administered to the students. When they finished studying all three lessons, the Textbook-Based Problem-Solving Test was administered. Students were also given the immediate Recall Test and then the Images of Three Scientists Survey. In Week 2, the posttests were administered in the following order: the delayed Recall Test followed by the Complex Problem-Solving Test and the Images of Scientists Survey. The total time spent completing the online lessons was about an hour, and the time spent completing each of the instruments is shown in Table 1. The head of the Research Division, who administered the study, ensured that there was no time difference among the three groups in completing each task for the treatment, as well as each of the instruments. To ensure validity of the study, students were instructed not to discuss the study with others during the 2-week period—if the three groups were learning from one another over 2 weeks, they should at least perform equally well. However, the findings below show this was not the case.

Results

To demonstrate comparability of the three treatment groups at the outset, a one-way MANOVA was performed using student grades of all major subjects available from the previous semester (i.e., Chinese, Math, and Science) as dependent variables. The results showed that there was no significant difference among groups, Wilks's $\lambda = .976$, $F(2, 268) = 1.10$, $p > .05$, $\eta^2 = .012$, observed power = .44. Further, in order to demonstrate invariance in measures between male and female participants before pooling all analyses by gender, another one-way MANOVA was performed, and the results showed no significant difference between gender in all subjects, Wilks's $\lambda = .989$, $F(2, 268) = 0.97$, $p > .05$, $\eta^2 = .011$, observed power = .26. In the following sections, we describe the findings for each research question (see Table 4 for a complete summary of the findings). To avoid capitalizing on chance, all analyses considered a *p* value less than .01 as statistically significant.

Images of Scientists

Images of scientists in general. To investigate the effects of different types of background information on students' general perceptions of scientists, an integrative 2 × 3 (image assessment by treatment) repeated-measures ANOVA was performed. As Table 4 shows, it yielded no significant interaction effect between image assessment and treatment, $F(2, 268) = 1.54$, $p > .05$, $\eta^2 = .011$, observed power = .33. But there was a significant effect in terms of image assessment, $F(2, 268) = 13.32$, $p < .001$, $\eta^2 = .047$, observed power = .95, in which the preassessment image scores were higher than the postassessment image scores. The findings indicate that the three lessons had impact on students' images of all scientists in general. Moreover, there was a significant effect in terms of treatment, $F(2, 268) = 10.23$, $p < .001$, $\eta^2 = .071$, observed power = .99, in which the struggle-oriented BI group outperformed the control group (Scheffe's post hoc, $p < .01$). The findings indicate that the students in the struggle-oriented BI group held more positive images of scientists than did the students in the control group.

Images of the three scientists (Galileo, Newton, and Einstein). There were three specific kinds of mental representations that emerged from open coding: achievement oriented, ability oriented, and struggle oriented. A one-way MANOVA was employed using the three image scores as combined dependent measures. The test revealed an overall significant difference among the three treatment groups, Wilks's $\lambda = .702$, $F(2, 268) = 17.15$, $p < .001$, $\eta^2 = .162$, observed power = .99. Specifically, as shown in Table 4, there was a significant difference among groups, $F(2, 268) = 16.22$, $p < .001$, in terms of achievement-oriented images, in which the achievement-oriented BI group scored higher than the struggle-oriented BI group (Scheffe's post hoc, $p < .001$) and the no BI control group (Scheffe's post hoc, $p < .001$). Thus, the achievement-oriented BI group's perceived images of the three scientists were more achievement oriented. There was no significant differences among groups, $F(2, 268) = 2.78$, $p = .06$, in terms of the ability-oriented images. There were significant differences in students' perceived struggle-oriented images, $F(2, 268) = 33.43$, $p < .001$. A Scheffe's post hoc analysis further showed that the students in the struggle-oriented BI group scored higher than both the achievement-oriented BI group ($p < .001$) and the no BI control group ($p < .001$). Thus, the struggle-oriented BI students' perceived images of the three scientists were more struggle oriented.

Students' Interest in Physics Lessons

On the basis of students' self-reports of whether they were personally interested in science, students were classified as either having lower level personal interest in science ($n = 142$) or higher level personal interest in science ($n = 129$). As a baseline comparison, a one-way ANOVA was conducted to examine how students with different levels of personal interest rated their interest in the online physics lessons. There was a significant difference between the two types of student with regard to the ratings of their interest in the online physics lessons, $F(1, 269) = 29.33$, $p < .001$, $\eta^2 = .098$, observed power = .99. Students with lower level personal interest rated the physics lessons as significantly less interesting ($M = 3.12$, $SD = 0.55$) than did students with higher level personal interest ($M = 3.48$, $SD = 0.54$).

Moreover, an integrative two-way ANOVA—three levels of treatment by two levels of personal interest—was conducted, yielding a significant interaction effect between treatment and students' personal interest level, $F(2, 265) = 6.34$, $p < .01$, $\eta^2 = .046$, observed power = .90. As shown in Table 4, further tests of simple main effects revealed (a) that for students initially with higher level personal interest in science, providing them with background information (regardless of struggle or achievement orientation) produced no significant differences among groups in terms of their interest in the physics lessons; (b) that among students with lower level personal interest, the struggle-oriented BI group perceived the physics lessons as more interesting than did the control group (Scheffe's post hoc, $p < .01$), while there were no significant differences between the achievement-oriented BI group and the other two groups; and (c) that specifically within the control group, students with higher level personal interest perceived the physics lessons as more interesting than did students with lower level personal interest (Scheffe's post hoc, $p < .01$). The above findings suggest that, for students with lower level personal interest in science, the exposure to scientists' struggle-oriented BI had a significant positive effect upon their interest in the online physics lessons.

Students' Learning in Science

Recall. An integrative 2 × 3 (recall by treatment) repeated-measures ANOVA was performed on the immediate and delayed Recall Tests. As Table 4 shows, it yielded a significant interaction effect between recall and treatment, $F(2, 268) = 14.26$, $p < .001$, $\eta^2 = .096$, observed power = .90. Further tests of simple main effects were conducted and revealed (a) that in terms of delayed recall, the struggle-oriented BI group outperformed the control group (Scheffe's post hoc, $p < .01$), and (b) that within the struggle-oriented BI group, students' performance compared to that of the other groups was significantly better in the delayed Recall Test than in the immediate Recall Test (Scheffe's post hoc, $p < .01$). These findings suggest that the struggle-oriented BI was useful in helping students retrieve information about key concepts in their science learning 1 week later.

Problem solving. Using the Textbook-Based Problem-Solving Test and the Complex Problem-Solving Test as multiple dependent variables, we conducted a one-way MANOVA to compare the three treatment groups, and it found an overall significant difference, Wilks's $\lambda = .824$, $F(2, 268) = 13.58$, $p < .001$, $\eta^2 = .092$, observed power = .99. Specifically, as shown in Table 4, in terms of textbook-based problem solving, the results revealed no significant difference among the three groups, $F(2, 268) = 0.57$, $p > .05$, $\eta^2 = .004$, observed power = .14. But, in terms of complex problem solving, there was a significant difference among the three groups, $F(2, 268) = 26.52$, $p < .001$, $\eta^2 = .165$, observed power = .99. Further, Scheffe's post hoc test revealed that the struggle-oriented BI group outperformed the achievement-oriented BI group ($p < .001$) and the control group ($p < .001$).

Summary of Results

The major findings are summarized as follows:

1. When students were exposed to achievement-oriented BI, they were more likely to develop more achievement-oriented images about the three scientists (Galileo, Newton, and Einstein) introduced in the physics lessons. In contrast, when students were exposed to the struggle-oriented BI, they were more likely to retain more positive images of all scientists and to develop more struggle-oriented images of the three scientists who struggled and worked hard to attain important scientific discoveries.

2. For students initially with higher level personal interest in science, providing them with background information (regardless of struggle or achievement orientation) had a neutral effect on their interest in the physics lessons introduced in the study. In contrast, for students initially with lower level personal interest in science, the two types of background information had different effects: (a) The achievement-oriented BI had a neutral effect on students' interest in the physics lessons, and (b) the struggle-oriented BI increased the students' interest in the physics lessons.

3. The achievement-oriented BI produced no effect on students' immediate and delayed recall of key scientific terms in the physics lessons. In contrast, while struggle-oriented BI did not affect students' immediate recall, it significantly enhanced students' delayed recall of key terms a week later.

4. The achievement-oriented BI provided no obvious help for students to solve both textbook-based problems and more complex open-ended science problems. In contrast, while the struggle-oriented BI had no impact on textbook-based problem solving, it did help students solve more complex problems that required a deeper understanding of the relationships among different scientific theories and laws.

Discussion

Images of Scientists

A half century ago, Mead and Metraux (1957) surveyed students' images of scientists nationwide in the United States; their findings, and other findings since then, consistently revealed stereotypical images of scientists. For example, students tend to depict scientists as wearing lab coats and eyeglasses and having facial hair (Barman, 1997; Chambers, 1983) and as being highly intelligent (Beardslee & O'Dowd, 1961; Souque, 1987), perfectly rational and emotionless (Brush, 1979; Kirschner, 1992), and antisocial and uninterested in people (Beardslee & O'Dowd, 1961; Driver, Leach, Millar, & Scott, 1996). Similarly, based on the findings on the images of the three scientists Galileo, Newton, and Einstein, our study also suggests that the content-driven science curriculum tends to reinforce achievement-oriented, stereotypical images of scientists. It may be assumed that the more students know about the scientists, the more likely it is that they will develop more realistic images of these scientists. Our findings, however, suggest this is not necessarily the case. Depending upon the kind of background information to which students were exposed, their perceived images of scientists can be very different. As our findings suggest, exposure to a scientist's achievement-oriented BI is likely to lead students to perceive scientists and scientific discoveries in an even more stereotypical manner. In contrast, when students are given opportunities to learn more about scientists' struggles, they are more likely to see scientists as ordinary people who encounter challenges and struggle in their scientific discoveries. The two different types of background information seemed to let students formulate different images of scientists, either as exceptionally bright people who can solve any problem without struggle or as ordinary people who have to work hard to achieve successful outcomes. These different images had important impacts on students' learning and problem solving.

Previous research suggests that the degree to which students' images of scientists fit the stereotype correlates with students' negative attitudes toward science as a major or a career (Brush, 1979; Lewis & Collins, 2001; Mead & Metraux, 1957). Moreover, students with stereotypical images of scientists are also less likely to see science as a human and social enterprise and to be less scientifically literate (Klopfer, 1969). These stereotypes discourage students from learning science by convincing them that scientists are not like them and are not the kinds of people they would like to be. The struggle-oriented BI, however, helps reduce such stereotypes among students.

Interest in Physics Lessons

Our findings revealed that students' interest in the physics lessons can vary depending on the level of students' initial personal interest in science and the type of background information that is provided to them. On the one hand, when the level of students' prior personal interest in science was already high, neither achievement-oriented nor struggle-oriented BI had any effect on students' interest in learning physics. One explanation for this is presumably a ceiling effect. As these students were already highly motivated in science learning, providing them with background information about the scientists (regardless of which type) became less useful.

On the other hand, the students with low initial interest in science benefited more from the struggle-oriented BI, since it increased their interest and confidence in learning the physics. As discussed in the introduction, interest can be generally divided into two types (i.e., personal and situational interest), and text-based interest is a kind of situational interest. Kintsch (1980) further described two types of text-based situational interest: cognitive and emotional. A text may be interesting because of the intricate pattern of events that is described (i.e., cognitive interest). Or, a text may appeal to the reader because of its direct emotional impact (i.e., emotional interest). Struggle-oriented BI likely aroused both types of text-based interest; therefore, the struggle-oriented BI particularly enhanced the overall interest rating of the lessons among students with low interest in learning science. In contrast, the achievement-oriented BI did not benefit students with low interest in science. We offer two possible explanations. First, the description of scientists' achievements did not reveal how the science content they were learning had been created. Second, the achievement stories are more emotionally neutral. Consequently, the achievement-oriented BI neither helped students better understand the three physics lessons (thus no arousal of cognitive interest) nor did it make the students more excited about learning science (thus no arousal of emotional interest).

Recall

In our study, the achievement-oriented and struggle-oriented BI had different effects on students' recall of key concepts covered in the physics lessons. The achievement-oriented BI had no significant effects on either immediate or delayed recall. One possible explanation is that the portrayal of scientists' achievements was less interesting because it did not reveal the processes of how the scientists struggled during their discoveries. It is less personal in the sense that it did not depict much about the scientists' personalities, working styles, or emotional struggles. It presented facts about the scientists' work, not about their personal lives.

In contrast, the struggle-oriented BI group performed better in the delayed Recall Test than in the immediate Recall Test. The personal struggle-oriented BI is more likely to help students build connections between different key concepts and thus to provide students with multiple access points. This facilitated the retrieval of their prior memory at a later point. Another possible hypothesis is that the struggle-oriented BI is more likely to elicit stronger cognitive and emotional reactions from the students than the achievement-oriented BI. This may motivate students to learn the knowledge generated by these scientists, which helped the delayed recall. Further studies, however, are necessary to test this hypothesis.

Previous research suggested that personal background information may be harmful to recall because the details distract people's attention from the content knowledge (Garner et al., 1991; Harp & Mayer, 1998). In our study, the personal background information (regardless of which type) produced no significant differences in students' immediate recall in either the achievement-oriented BI or struggle-oriented BI conditions. This could be because the personal background information may be interesting enough to draw students' attention to the content knowledge.

Problem Solving

In order to successfully solve the complex open-ended problems, students needed to identify, elaborate, and make connections among several scientific laws/theories. For example, in addressing the question concerning the relationship between Galileo's law of inertia and Newton's first law of motion, significantly more students in the struggle-oriented BI group were able to identify common mechanical variables shared by the two laws. Moreover, there were also more struggle-oriented BI students who were able to articulate the evolutionary relationships between the two laws. For example, many students mentioned that Galileo's theory of inertia was not fully developed at first but was further improved upon later by Newton and that while both laws defined inertia, they are actually two different theories along a theory-building continuum.

Our study also raised questions of why personal background information produced no impact on the well-defined textbook problem solving yet affected the complex problem solving. One reason may have to do with the nature of textbook problems. As commonly observed in most formal science instruction, textbook problems are often designed with predetermined, fixed answers that require an understanding or application of only one specific scientific law or theory. In the present study, knowing a specific theory or law was sufficient to solve the textbook problems but not enough for the complex problems. Even though both types of background information contain rich contextual information, this information is not necessary for solving the textbook-based problems. However, to solve the complex problems, it was essential for students to be able to recognize the theories/laws learned from different physics lessons as being interrelated, rather than as being independent. It is highly likely that the struggle-oriented BI allowed the students to see the interconnections among different theories and laws because the struggle-oriented BI reveals both the processes and struggles the scientists experienced to achieve their discoveries. As such, the struggle-oriented BI helps students understand how, why, and under what conditions specific laws or theories were developed; this contextual understanding is crucial for complex problem solving. Similarly, solving complex physics problems would require students to view learning not as a process of acquiring discrete facts about scientific theories/laws but as a process of developing a relational understanding of how theories are conceptually related to one another and improved through sustained knowledge building (Hong, 2011; Hong, Scardamalia, & Zhang, 2010; Hong & Sullivan, 2009; Zhang, Hong, Scardamalia, Teo, & Morley, 2011). The findings suggest that struggle-oriented BI is more likely than achievement-oriented BI to provide students with opportunities to learn from scientists' theory-building process in a more holistic manner.

Limitations and Future Directions

Admittedly, there are limitations to this study that must be recognized. First, there is a need for a greater consideration regarding generalizability from a single school in Taiwan. Although some scholars (e.g., Cobb, 2001; Steffe & Thompson, 2000) have argued that studies grounded in analyses of a small number of classrooms can be generalizable, as insights developed from such analyses can inform the interpretation of instruction in similar contexts, future research should be conducted in more diverse cultural contexts. Second, the selection and operationalization of the struggle-oriented instruction may be based on more specific criteria. In the current study, we adopted the general definition of *struggle* from the *Oxford Dictionary*, meaning to "strive to achieve or attain something in the face of difficulty or resistance" ("Struggle," n.d.). However, we did not differentiate scientists' intellectual struggles in science from their personal/social struggles in life in general. It is unclear if different types of struggle stories will have different levels of impact on students' learning. Perhaps the intellectual struggles, which were most similar to students' struggles in school, are most effective in increasing motivation in the classroom. While the personal life struggles may be most interesting to students, these stories do not offer models for how to deal with learning-related struggles. However, some students may need these personal stories to feel that they can relate to the scientists. For future research it may be helpful to examine the effects of more distinct types of struggles on students' science learning. Third, regarding the measures, the Interest in Physics Lesson Survey was self-developed and tested among Taiwanese students. So it is not clear how well the results will generalize to different cultural contexts.

In the present study, we administered the Textbook Problem-Solving Test as an immediate test and the Complex Problem-Solving Test as a delayed test. We did this because we posited that contextual information would not have any effect on textbook problem solving and that for contextual information to have any effect on complex problem solving, it would require more reflection time. To substantiate this claim, future studies would do well to administer both tests after a delay or to administer them both immediately and after a delay. Fourth, while personal background information proved to be beneficial to science learning, it would be necessary to further investigate if the same effects (i.e., students' aroused interest in physics lessons) can last over a longer period of time. Moreover, it is also important to document the processes of how exposure to the scientists' struggles enhances students' thinking and problem-solving strategies, which led to effective complex problem solving. In the present study, we did not document the specific strategies that students developed or employed to solve complex problems. Finally, it is plausible that long-term exposure to struggle-oriented BI could change students' core perceptions from a more static and absolute viewpoint to a more dynamic and relative view of scientific knowledge. Accordingly, we also speculate that long-term exposure to struggle-oriented BI about scientists should have a positive influence on the development of students' personal identities. It would be interesting to investigate how students view scientists as people to whom they can relate, whose behaviors and attitudes they emulate. Even further, this exposure may affect how students view themselves as science learners as well as potential future scientists and how students regard science as a possible career choice or college major.

Conclusion

In conclusion, our study offers several implications for science education and curriculum development. First, a long-standing challenge in science education has been to overcome students' stereotypical perceptions of scientists. Our findings suggest that science instruction can help address this issue by providing students with opportunities to learn more about scientists; to get to know them as people who have challenges, struggles, and emotions; and to gain a perspective of how and why they struggled to keep improving theories and creating new knowledge. These practices will help decrease stereotypical images of scientists that students have developed as a result of popular culture or mass media portraying scientists as innate knowledge vessels.

Second, the declining interest and self-confidence in science as a major has become a major challenge for educators and policy makers (Osborne, Simon, & Collins, 2003). To help address this issue, science instruction should try to capitalize on scientists' personal background information, particularly the struggles scientists have experienced during their scientific discoveries. Doing so would increase scientists' overall social presence and students' social interest in these scientists (Dewey, 1913). This is especially important for the design of technology-based learning environments, as these environments tend to overemphasize the visual effects of multimedia affordances while overlooking humanistic aspects (Lin, 2001; Lin & Schwartz, 2003). As this study suggests, the struggle-oriented BI should add a human touch to the technological design of online learning environments, therefore making science learning more humanly interesting and inspiring.

Finally, as our findings suggest, students can better acquire scientific knowledge if the scientists producing this knowledge are made more approachable. There are two related implications of this view. One is that science instruction should provide students with more learning opportunities to both organize and create knowledge around people. It should focus not only on abstract scientific concepts but also on the scientists who struggled to develop these concepts. The other is that it may be worth investigating whether conventional person-neutral science curricula should integrate, and make better use of, struggle-oriented BI. By helping students see the real human struggles behind science, we can inspire greater interest and learning to benefit future generations of scientists.

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Appendix A

Achievement-Oriented and Struggle-Oriented Background Information About Galileo (Translated From Chinese)

Achievement-Oriented Background Information About Galileo

1564	Birth of Galileo Galilei in the Tuscan city of Pisa.
1572	Beginning of formal education.
1581	Galileo enters the University of Pisa.
1583	Galileo formulated the idea of an equal duration of the pendulum swing while watching the oscillations of a lamp in the cathedral of Pisa.
1585–1589	Gives private lessons in mathematics in Florence and Siena.
1586	Galileo begins to work on certain problems in physics. He invents a hydrostatic balance.
1589	Teaches mathematical subjects at the University of Pisa.
1590	Galileo begins a book, *De motu* (*On motion*), which is never published.
1590	Galileo reportedly makes his famous velocity experiment, dropping objects off the leaning tower.
1592	Galileo takes a post at the University of Padua.
1592–1610	Galileo's most productive period of time. For example, he invents a machine for raising water.
1597	Invents a "geometric and military compass."
1604	The new star (supernova) is first observed in Padua. Galileo debates its significance with conservative scholars.
1606/1607	Invents the thermoscope, a primitive thermometer.
1607/1608	Further studies on motion. Discovery of the parabolic path of projectiles.
1609	News of the invention of the telescope reaches Italy. Galileo makes his first observations using his telescope, discovers uneven surface of the moon.
1610	Galileo discovers four moons orbiting Jupiter.
1610	Galileo is appointed Chief Mathematician of the University of Pisa and Philosopher and Mathematician to the Grand Duke of Tuscany.
1610	Galileo first observes the strange appearances of Saturn.
1613	*History and Demonstrations About Sunspots and Their Properties* is published.
1616	Papal commission issues edict against Copernican theory; Cardinal Bellarmine orders Galileo to cease in his support of heliocentricity.
1633	Galileo is interrogated for the first time. Afterward, he is imprisoned in the Vatican for three weeks.
1634	Galileo is allowed to return to the village of Arcetri, outside Florence, where he lives under house arrest.
1635	A Latin translation of the *Dialogues Concerning Two New Sciences* is published.
1638	Galileo's *Dialogues Concerning Two New Sciences* is published in Holland.
1642	Galileo dies in Arcetri on 8 January.

Struggle-Oriented Background Information About Galileo

According to Aristotle, the speed of a falling body is proportional to its weight. That is to say, a 10-pound object will fall 10 times faster than a 1-pound object. During Galileo's time, this theory was considered to be true. No one ever doubted it.

However, this was not what Galileo observed during a hailstorm, in which he noticed that both large and small hailstones seemed to fall at the same speed and hit the ground at the same time. On the basis of this observation, Galileo later did a lot of experiments and he found Aristotle's theory was incorrect. This inspired Galileo to disprove Aristotle's theory.

According to legend, Galileo performed one experiment by throwing two boulders of differing weights off the Leaning Tower of Pisa in front of his students and colleagues. As he had predicted, the two boulders fell simultaneously and then hit the ground at the same time. Although the experiment was successful, it did not dissuade people from believing in Aristotle's theory.

In order to make his experiment more precise, Galileo then thought of many ways to mathematically measure the speed of a falling body. However, none of them worked because under the influence of gravity, the motion of objects was too quick.

The technology during this period was inadequate to measure acceleration accurately. Finally, after continuous trials, Galileo thought to work with inclined planes. He came up with an interesting idea to slow down or cancel the gravity effect by using inclined planes, so he could observe and measure the rate of acceleration. Galileo used the inclined planes to prove his law of free fall, which states that distance traveled is proportional to the square of time.

In addition, in his experiments on inclined planes, he also found that when a ball was rolling down a hill it would pick up speed because gravity would pull it down faster, and as soon as the ball reached the flat part of the hill it should continue rolling until it is acted upon. But we know that it would stop because friction would be the force acting on it. This idea is the basic idea on which inertia is based.

Galileo dedicated his whole life to scientific research in pursuit of truth. He had countless scientific discoveries. He even invented the telescope, which he developed in collaboration with Paolo Sarpi. Galileo died in 1642.

(*Appendices continue*)

Appendix B

Items in the Interest in Physics Lesson Survey

1. The topic of this article is interesting.
2. The article as a whole is interesting.
3. This article is easy to understand.
4. I understand the laws or theories described in the article.
5. I enjoy learning the laws or theories described in the lesson.
6. I like the examples given in the lesson.
7. I would recommend this article to my friends.
8. I would like to study another similar article.
9. I know better now the scientist introduced in the lesson.
10. I like the scientist in the lesson more than before.
11. The scientist in the lesson helped me understand better what science is.
12. I understand better now the personality of the scientist in the lesson.
13. The scientist in the lesson helped me learn how to do research.
14. I like science more because of the scientist in the lesson.

Appendix C

Open-Ended Questions in the Complex Problem-Solving Test

1. How would you describe the relationships between Galileo and Newton in terms of their theory development?
2. What is the relationship between the law of inertia and Newton's first law of motion?
3. What is the relationship between an inclined plane and the law of free fall?
4. How is Galileo's law of free fall related to Newton's theory of gravity?
5. How would you describe the relationships between Newton and Einstein in terms of their theory development?
6. How would you describe the relationship between Newton's law of gravity and Einstein's theory of relativity?
7. How is Einstein's theory ($E = mc^2$) related to the law of conservation of energy and the law of conservation of mass?

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