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Encouraging a "Romantic Understanding" of Science: The Effect of the Nikola Tesla Story

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Abstract The purpose of this paper is to discuss and apply the notion of romantic understanding by outlining its features and its potential role in science education, to identify its features in the story of Nikola Tesla, and to describe an empirical study conducted to determine the effect of telling such a story to Grade 9 students. Elaborated features of the story are the humanization of meaning, an association with heroes and heroic qualities, the limits of reality and extremes of experience, a sense of wonder, and a contesting of conventions and conventional ideas. The study demonstrates the learning benefits of encouraging a romantic understanding through a story that is structured explicitly around the identified features, in this instance in the context of the production and transmission of alternating current electricity. Quantitative and qualitative analyses of journal entries showed that the group of students who were encouraged to understand the concept of alternating current romantically (the experimental group) became more involved with both the content and the context of the story than a comparison group of students who were taught the concept explicitly, without a context (the control group). The students in the experimental group also performed statistically better on a science-content test taken one week and again eight weeks after the indicated teaching intervention. This finding, along with the content analyses of students' journals, provided evidence of romantic understanding of the science content for those students who listened to the Tesla story.

1 Introduction

In recent decades, with the focus in mainstream science education having been on conceptual understanding, the notion of a romantic understanding of science would have seemed naïve, if not absurd (Schulz 2009). Even nowadays, this idea may raise arguments on metaphysical and epistemological grounds. While it is not unusual for someone to describe a sunset romantically or to experience it in a poet's work, it is uncommon to read about a physicist's romantic understanding of a sunset. While each of these descriptions has aesthetic dimensions, the physicist's understanding of it differs markedly, not only in terms of the language used, but also in the process of understanding (Hirst 1972), which employs the approach of looking for connections among facts, phenomena, concepts, and ideas, searching for patterns, and applying known laws to explain observations.

Generally, a concept or an idea, in order to be understood, needs to be placed in relationship with

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other concepts or ideas (for example, as in a concept map) and applied in a variety of contexts.[1] Popper (1972) points out that in order to understand a concept, its historical origin and evolution have to be understood, as well. The desirability of considering concepts in context, however, does not negate the fact that science, itself, has an aesthetic dimension, allowing for a physicist's aesthetic experience and understanding of a phenomenon or an idea.[2] While some seasoned scientists might have forgotten how to appreciate their craft aesthetically, young students are spellbound by the romantic nuances that they perceive in the science to which they are exposed. It is, therefore, reasonable to consider the idea of a romantic understanding of science and its implications for science curriculum and teaching.

A. N. Whitehead (1929), in talking about the rhythm of education, identified three stages in learning, namely, romance, precision, and generalization. He maintained that any subject of study first needs to be approached in a romantic way before it is studied in some depth with precision; then students are able to apply their ideas, which involves generalization. Whitehead's stage of romance could be described as "romantic engagement," which should be distinguished from the idea of "romantic understanding" as elucidated in this paper. Romantic engagement is the starting point for the development of a romantic understanding. In this sense, romantic engagement could be considered the impetus for learning science, whereas romantic understanding emerges as the subject matter is explored in greater depth, which inevitably leads to the stages of precision and generalization.

Whitehead's (1929) three-stage model acknowledges the role of motivation in understanding, and other research findings support its role in learning (Franken 2001; Ormrod 1999; Pintrich and Schunk 1996). While not particularized to the students' understandings of the world at specific ages, Kieran Egan's (1997) recapitulation theory, however, addresses this latter issue.[3] According to Egan, people make sense of the world in five distinctive ways, which he calls forms or kinds of understanding. He conceives education as a process during which students recapitulate, that is, repeat in the same order, different kinds of understandings—somatic, mythic, romantic, philosophic, and ironic—in the sequence in which they have appeared in our cultural history. Each kind is best developed at particular ages when students learn to use an array of mental strategies or cognitive tools, as Egan refers to them, that are characteristic of each kind of understanding. These kinds of understanding, not to be confused with the Piagetian stages of cognitive development occurring at certain ages by some psychological impulse, are produced when students acquire certain sets of cultural tools that, through their use, are converted into cognitive tools. With the exception of somatic understanding (knowing through the physical senses), all the other types of understanding are language-dependent—our "language engagement" with the world.

1.1 Purpose

The purpose of this paper is (a) to examine the concept of romantic understanding from the perspective of Egan's (1997) theory by outlining its features and its potential role in science education, (b) to present a romantic framework that can be used to bring the story of Nikola Tesla into the classroom, (c) to examine the effect of the Tesla story on students' understanding of the concept of alternating current (AC) electricity, and (d) to examine the effect of the Tesla story on the development of a "romantic understanding" of the concept of alternating current.

2 The Notion of Romantic Understanding

It is commonly observed that children develop oral skills approximately between the ages of two and seven years and literacy skills approximately between the ages of eight and fifteen, with these

[1] See AAAS, 1990; Mintzes Wandersee, and Novak 1997; Resnick 1983; Klassen 2006.
[2] See Girod 2007; Root-Bernstein 2002; Tauber 1996; Wong, Pugh, and the Dewey Ideas Group at Michigan State University 2001.
[3] Egan's theory is elaborated in Section 2.

developments often overlapping. Children's abilities for abstract reasoning (also entailing a conceptual understanding) emerge somewhat later than the basic literacy skills even though abstract reasoning at earlier ages is common. According to Egan, during these various phases in their development, children view the world with progressively more sophisticated cognitive strategies, which he denotes as "understandings." During the early linguistic period, children develop a mythic understanding, its main characteristics being the emphasis of fantasy, the recognition of mystery, and the use of binary opposites, storytelling, mental imagery, and humor (Egan 1997).

Romantic understanding (Egan 1997) is the transitional phase between a mythic and conceptual understanding ("philosophic" in Egan's terminology). It may be defined[4] as the ability to grasp meaning, in a humanistic context, of the features of subject matter that tend to be idealistic in expectation and glamorously imaginary and involve the exotic and the potential for heroic achievement, as the term "romantic" suggests. During the period of romantic understanding, children are attracted, for example, to literary characters who do heroic, but possible, things. While they are beginning to interpret the world from an abstract perspective, they still retain some aspects of the mythic understanding. This transitional phase gains significance when one realizes that neither Donald's (1991) distinction between mythic and rational thinking nor Bruner's (1986) distinction between narrative and paradigmatic (or logico-mathematical) thinking offers an explanation for the transitional stage from mythic or narrative understanding to rational or paradigmatic understanding.

Egan (1990, 1997) expanded his notion of romantic understanding by identifying five vital means through which children, at this stage, make sense of the world and of experience. These devices, by which they mediate between the world and the mind, are referred to as "cognitive tools" by Egan (2005a, b) and become the specific characteristics (1997) of romantic understanding: (a) the humanization of meaning, arising from the realization of the humanistic dimension of all knowledge, (b) an association (even identification) with heroes and heroic qualities, (c) a focus on and confrontation of the extremes and limits of reality and experience, (d) a sense of wonder, and (e) the contesting of conventions and conventional ideas.[5] Several decades of research and refinement in this area have resulted in the characteristics that appear here. These five aspects also emerge naturally from our earlier definition of romantic understanding. They serve to enlarge students' ability to think and understand, and the larger the number of tools that a student uses, the better will be the understanding that is gained.

The notion of a "cognitive tool" makes the distinction between narrative and romantic understanding apparent. While narrative understanding is a natural kind of understanding that, under minimal contextual constraint, comes spontaneously into being (Bruner 1985), the development of a romantic understanding requires and, in fact, presupposes the use of an array of specific cognitive tools beyond those that characterize narrative understanding (e.g., similes, paradoxes). Egan's (1997) idea of a cognitive tool is broader than Vygotsky's, which focuses largely on oral language. Egan (2005a, b) includes a range of cognitive tools that may accompany both oral and written language.

2.1 Fostering Romantic Understanding

If one is to foster a romantic understanding in an instructional setting through the application of the relevant cognitive tools, it is necessary to devise a means to operationalize the concept. A tentative operational definition of romantic understanding is the motivating insight that emerges through the combined engagement of the emotions and intellect in response to a specialized text. In our study, the instructional strategy of the story is the "specialized text," which incorporates the various cognitive tools. These tools, as applied in the study, are elaborated, below.

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4 Our definition is an interpretation of Egan's work.
5 Egan uses the term "revolt against convention."

2.1.1 Humanization of meaning

The humanization of meaning is an all-important tool for enabling students to see knowledge through human emotions. Through the use of this tool, students grasp the deeper human meaning of what they are supposed to learn. To put this tool to use, students need to become aware of the human context of the knowledge and content to be learned. Egan (1997) contends that since all knowledge is, actually, human knowledge, it cannot be separated from the hopes, fears, ambitions, and struggles of those who created it; in other words, "[t]o bring knowledge to life in students' minds, we must introduce it to students in the context of the human hopes, fears and passions in which it finds its fullest meaning" (Egan, 2005b, p. xii). Humanization of meaning is facilitated, in part, through the use of the other cognitive tools; for example, a student, in associating with Galileo's heroic quality (i.e., the pursuit of scientific truth despite the possibility of his being sentenced to death), inevitably becomes aware of the human context of scientific knowledge. So, although humanization of meaning is a distinctive tool, other tools may well facilitate its development so long as those tools help to generate an awareness of the human context in which knowledge was developed.

2.1.2 Associating with heroic elements and qualities

Using the learning tool of associating with heroic qualities exemplified by heroes allows students to gain confidence in dealing with harsh reality and to realize that they, too, can face and deal with the real world. When children move from orality to literacy, hence from a magical to a more realistic world view (Egan 1997), they feel threatened—especially teenagers, who are preoccupied with issues such as success in school and in life, getting along with others, and being liked by the their peers and individuals of the opposite sex. The resulting sense of insecurity, according to Egan (1997), can be counteracted by transcending reality, that is, by associating or identifying with important human qualities or values exemplified by notable individuals. Young people gain confidence that they, themselves, can possess heroic qualities and, as a result, tend to associate with success-producing traits.

Egan (1997) identifies heroic qualities such as tenacity, boldness, and courage, as well as others that are often associated characteristics, such as extraordinary creativity and ingenuity. The courageous act, indeed, is often a defense of a highly creative idea that has challenged a mainstream belief and has suffered aggressive rejection. Because all these admirable human—or even seemingly superhuman—qualities are embodied by certain people, like rock stars, sports heroes, or even scientists, (any of whom may not be deemed heroes in the strict sense of the word), students naturally tend to identify with them as models of success and triumph, and even though the students may not expect to achieve the same status as their heroes, they, nevertheless, tend to emulate them. A youngster might associate more easily with creativity than with courage when the latter quality may have put the life of the hero at risk (as, for example, Galileo); however, even in the case where the heroic quality is genuinely transcendental, inspiration may be derived from that quality.

2.1.3 The extremes of reality and human experience

Extremes of reality and human experience is a vital cognitive tool of romantic understanding that enables students to gain security and confidence in dealing with reality by establishing the limits of the environment and its most outstanding features. Their preoccupation with extremes and limits, such as are recorded and described, for example, in *The Guinness Book of Records*, explains young people's attempt to understand proper scale and norms and, thereby, what is possible or impossible for them to achieve. As Egan (1997) points out, if reality were infinite, then it would be a challenge to find security and create meaning. Establishing the limits of any new environment creates a sense of security in that situation and enables meaning to be formed.

Focusing on extremes and limits is crucial for imaginative engagement and makes us reconsider the idea that teaching should always start from what is already known and familiar (Egan 1997; see also

Hadzigeorgiou 1999). Most youngsters at about the age of 10, even younger sometimes, are more interested in the unfamiliar, the distant, and the exotic. This idea was already pointed out clearly by Dewey (1998, pp. 288–289) in his book *How We Think*, which makes one question the current, prevalent teaching practice of starting the teaching-learning process with what is already familiar.

2.1.4 A sense of wonder

A sense of wonder is conceived as astonishment mingled with bewildered curiosity, admiration, and the awareness that one’s knowledge is incomplete or erroneous or that some extraordinary phenomenon exists. Wonder is an essential cognitive tool since it encourages involvement with the object of study (Hadzigeorgiou 2005b) and discourages what Dewey (1960) called “the spectator theory of knowledge,” a view that is still prevalent in constructivist teaching models (Dahlin 2001). Given that wonder has both an emotional and a cognitive dimension, its use as a learning tool is essential (Hadzigeorgiou 2008, 2011). Even in systematic theoretical inquiries, it is difficult to imagine that the activity could have begun without initial wonder (Egan 1997).

2.1.5 Contesting of conventional ideas and all kinds of conventions

As students enter adolescence, they tend to challenge the status quo more and more. While they begin to explore roles they will take in the adult world, they simultaneously resist those roles and seek greater freedom and independence from the rules and conventions that shape their everyday life. In the context of science teaching and learning, students question the required learning, prescribed by someone whose authority they also question, even questioning the current state of science. Contesting of conventions manifests itself in many other ways, such as wearing unusual hairstyles and disobeying rules. This characteristic, which may appear as negative on the surface, can become a cognitive tool that complements other tools (Egan 2005a) when students learn that knowledge is the result of a human struggle against a conventional idea. Science, especially, offers many opportunities for students to become aware of the barriers of convention that creators of new knowledge encountered.

2.2 Teaching for Romantic Understanding and its Evaluation

It is evident that in order for students to develop romantic understanding it is essential to utilize a teaching framework based on the use of its characteristic tools. Merely having such a teaching framework cannot, however, guarantee the development of romantic understanding in the learner. It is reasonable to expect that romantic teaching will likely result in the students’ romantic engagement with content knowledge; yet, the result could still be a conventional understanding of the content. The presence of a romantic understanding of content knowledge, therefore, requires evidence of the presence of the specific, distinguishable features of romantic understanding. The most direct way for the teacher or researcher to evaluate such understandings is to analyze the content of students’ journals for the presence of relevant romantic features. The incidence of romantic features that are intertwined with the content knowledge would comprise good evidence of a romantic understanding.

2.3 Romantic Understanding in Science Education

The question of how romantic understanding can be developed in the context of science education may be addressed from both a general and an explicit theoretical perspective. In general terms, it is relevant to consider Bruner’s (1985, 1986, 1990) two modes of thinking—the narrative and paradigmatic (or logico-mathematical)—which

> are two irreducible modes of cognitive functioning—or more simply, two modes of thought—each meriting the status of a “natural kind.” Each provides a way of ordering experience, of constructing reality and the two (though amenable to complementary use) are irreducible to one another. (1985, p. 97)

By “natural kind” Bruner (1985) means that each mode of thought, under minimal contextual constraint, emerges spontaneously. The paradigmatic mode is concerned with the formation of hypotheses, the development of arguments, and rational thinking, generally. The narrative mode, on the other hand, is concerned with “verisimilitude” or life-likeness and the creation of meaning. It seeks explications that are context-sensitive and particular (not context-free and universal). The narrative mode is entirely divergent and employs literary devices, such as stories and metaphors, in order to evoke meaning.

The narrative mode of thinking is important to science, as many scientific and mathematical hypotheses begin as stories and metaphors (Bruner 1986), and today’s science is built upon the scientific theories of yesterday which were, in many cases, built upon “prescientific myths” (Popper 1972, p. 346). Scientific maturity presupposes a process of conversion into verifiability—the essence of the paradigmatic or logico-mathematical mode. Although the narrative mode of thinking could be used to construct unreal or even impossible worlds, Bruner (1985) points out that “the narrative mode is not as unconstrainedly imaginative as it might seem to the romantic” (p. 100). In science, especially, we cannot construct an arbitrary world or all kinds of impossible worlds because the paradigmatic mode of thinking, a complementary kind of thinking, tests theories through the use of evidence, arguments, and so on. According to Egan, “rationality and reality are closely intertwined in our mental lexicon” (Egan 1988, p. 11).

In specific terms, the concept of romantic understanding, itself, provides the theoretical basis on which the concept can be developed in the science-education context. Based on Egan’s (1990, 1997) general conception, a romantic understanding of science can be described as a narrative kind of understanding that enables students to become aware of the human context of the science content to be learned by associating such content with the attributes of romantic understanding, as delineated. Although different from conceptual understanding, romantic understanding, nevertheless, relates to the science content, which often contains extremes, evokes a sense of wonder, and provides opportunities for associating the concepts with heroic qualities. It can also be associated with the contesting of conventions if such content involves scientists who struggled against conventional and prevailing ideas and beliefs (Hadzigeorgiou 2005a). The significance of romantic understanding in science education lies in its potential, on the one hand, to inspire students, and, on the other, to help them become aware of the emotional import of scientific ideas (Hadzigeorgiou 2005a, b).

2.3.1 The humanization of meaning

That all scientific knowledge is the result of human endeavor and that human emotions are inextricably linked to the creation of such knowledge are two key facts that emerge out of the history of science. Real events from scientists’ life and work abound and readily provide a context that helps humanize meaning in science content.

2.3.2 Heroic qualities

Heroic qualities, manifested in admirable character traits and abilities, permeate life and literature. As has already been elaborated above, students tend to identify with heroes on the basis of their praiseworthy qualities (e.g., Galileo’s persistent belief in a moving Earth, despite his fear of reprisal, even death; Tesla’s uncommon ingenuity in designing alternating current motors). They identify with them not in order to establish similarities between themselves and the heroes or even to aspire to achieve the same laudable status, but to form the conviction that they, too, can develop some of the same venerable human qualities. Listening to stories and seeing scientific achievements in those stories as heroic does not result in students despairing and thinking themselves incapable of doing science; rather, such activity enables them to share in the heroism by conceiving of it as a human possibility. For the same reason, some young teenagers who are inspired by sports and rock-music icons later pursue careers in soccer, hockey, or baseball and singing or playing an instrument. The Appendix provides evidence of students’ admiration and in some cases, emulation of Tesla’s heroic characteristics in response to hearing the Tesla story.

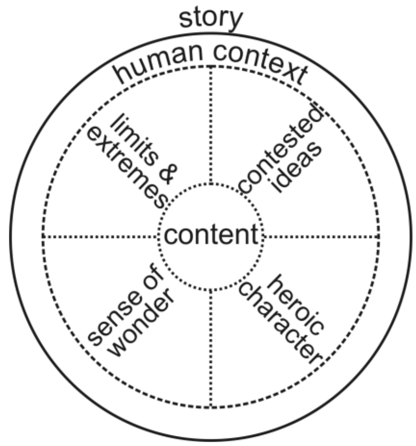

Figure 1: A framework for the development of romantic understanding

2.3.3 The extremes of physical reality

Regarding the extremes of physical reality, the fastest and slowest particle, the lowest temperature, the smallest electric charge, the brightest object, and the smallest amount of energy are some examples of extremes that can be associated with science content. Science content can also be associated with the extremes of human experience: the fastest person on earth, the longest long jump, the deepest dive, the longest flight, the fastest athlete, and so forth.

2.3.4 The wonder of science

The content of science is replete with phenomena and ideas that have the potential to foster a sense of wonder, from Newton’s law of action and reaction and the free fall of objects to the nature of electricity and matter and light. Wonder can be evoked in a variety of ways, the most prevalent being through verbal expression (e.g., light is invisible) or through a demonstration experiment (e.g., a tiny magnet can hold a paperclip, despite the fact the whole planet is acting downward on it). A sense of wonder, materialized through paradoxes, mysterious phenomena, and astonishing ideas that make students aware of their incomplete or mistaken knowledge, can help them see everything in a new light and emotionally charge the pieces of information to be learned.

2.3.5 Contesting of conventional ideas

Science content can be connected to the contesting of conventions if such content is associated with scientists who struggled against prevailing ideas and beliefs, as many did. Scientists such as Galileo, Boyle, Volta, Tesla, Einstein, and Marconi had to struggle against firmly established beliefs about motion, electricity, the existence of vacuum, the nature of gravity, the transmission of electric power, and electromagnetic waves.

2.4 A Framework for the Development of Romantic Understanding

In order to facilitate the development of romantic understanding, it is necessary for science teachers to identify heroic qualities that relate to the specific science content to be taught and to organize this content within a narrative structure. The heroic qualities, in particular, can capture the main narrative thread and, thereby, help maintain students’ attention from the beginning to the end of the lesson. The narrative should be crafted in such a way that the aspects of romantic understanding are inherent in the story: (a) the human context is used, (b) a sense of wonder is evoked, (c) some limits of reality and extremes of human experience are exposed, (d) heroic character traits are applauded, and (e) conventions and prevailing ideas are contested (see Fig. 1). The human context can be derived from the history of science, which will ensure that historic events and ideas are woven into the work, creating a story that meets the specified criteria. This context will facilitate the humanization of meaning, which is the central focus of romantic understanding.

The motivation for using storytelling in science teaching, by itself, does not guarantee that the guidelines for constructing teaching frameworks are appropriate or clear. Klassen (2009) maintains that creating good stories is a challenging task, especially so for science educators without a background in the humanities. The criteria for selecting or creating a story that fosters the development of romantic understanding should, however, not be identified solely with the elements of an engaging story (see De Young and Monroe 1996) or with the criteria of a "good story" (Klassen 2009; Kubli 2001). A story that fosters romantic understanding should be structured in such a way that, in addition to the elements of a "good story" (i.e., coherence, problematization, mystery, characterization, problem resolution, challenging previous knowledge, raising questions), the distinct characteristics of romantic understanding are taken into account.

2.5 The Nature of Science and Romantic Understanding

The development of romantic understanding can also facilitate learning about the nature of science (NOS) in that science tends to be partially subjective, is socially and culturally embedded, and involves human imagination and creativity (Lederman and Lederman 2004, p. 37). All of the characteristics of romantic understanding can promote the notion of science as a process that is an essentially human endeavor. It promotes the view that science has a personal dimension, for scientists have to confront and contest mainstream, traditional ideas in order for scientific progress to take place. In this respect, the contribution of romantic understanding is catalytic since there is strong evidence that science is not only a social activity—"constitutively social" as Woolgar, (1993 p. 13) put it—but also involves the aesthetic, often realized in experiencing awe and wonder (Tauber 1996; Root-Bernstein 2002). The vital qualities of science are often contained in its uncommon features, marked by individual variation amount scientists and their ideas (Wong 2002). In general, the idea of science as a personal endeavor—which includes the emotions, fears, hopes and ambitions, as well as the difficulties, problems, and struggles of scientists—can be advanced by encouraging a romantic understanding of science.

3 Romantic Elements of the Tesla Story

The story of Nikola Tesla is well known. His life and extraordinariness are unveiled in several books (e.g., Cheney 1981; Jonnes 2003; Lomas 2000), useful sources for those who associate Tesla's name merely with the magnetic induction unit. The idea of utilizing alternating current originated with Nicola Tesla, and his ultimate success came only after a long controversy and nasty battle. The battle, known as the "war of the currents," was finally won by Tesla in 1895 when, for the first time, he successfully transmitted power from Niagara Falls, New York to Buffalo, 21 miles away. It was an unthinkable feat in the world of direct current, one in which the Thomas Edison Company already had huge investments and enjoyed patent royalties.[6]

Greene (1978) has argued that, from time to time, it is necessary to respond to "shocks of awareness" (p. 185), and, when used for instructional purposes, the Tesla story can, indeed, give such a "shock of awareness" to many students and teachers. Moreover, it, like other stories, can help humanize science teaching and learning (see Hadzigeorgiou 2006) by revealing the human context from which scientific

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6 See Cheney 1981; Jonnes 2003; O'Neil 1992; Seifer 1998.

ideas emerge, particularly the role that controversy and persistence play in shaping and promoting such ideas. Pedagogically, Tesla’s life and work not only provide a romantic framework for the teaching and learning of alternating current but also encourage a “romantic understanding” of science. His life story, in and of itself, holds all the elements that are central to the development of a romantic understanding, as can be illustrated with a description of its primary elements—heroic qualities, extremes and limits of reality and human experience, current ideas contested, and a sense of wonder—according to the literature concerning Tesla’s life and work.[7]

The Tesla story, bearing all of the romantic elements, can be used to encourage a romantic understanding of current electricity and, specifically, of alternating current. The effect and the actual benefits of using the Tesla story are presented in Section 4 of the paper, which reports on the results of an empirical study with Grade 9 students.

3.1 Humanization of meaning

Based upon real events concerning his life and work, the story of Nicola Tesla makes it quite apparent that scientific knowledge (i.e., about alternating current electricity) was the product of a human pursuit motivated by personal ambitions, humanistic ideals, and a sense of social responsibility, as well as frustrations with the establishment, especially the perceived greed of rivals. The final victory of the idea of alternating current over that of direct current (the accepted technology of his time), is directly linked to Tesla’s character, his ambitions, and his humanitarian goal of providing free electricity to all people on the planet.

3.2 Heroic Qualities

According to the September 1997 special issue of *Life Magazine*, Tesla is among the 100 most famous people of the millennium who have helped to change the course of human history. In reading Tesla’s biography, one cannot help but admire and, in fact, be astonished at his qualities, talents, and mental powers, exemplifying four distinct heroic qualities—ingenuity, imaginative vision, will-power, and acute visualization capability.

Tesla’s innovation began with the realization that direct current was inefficient for transmitting electrical power over long distances. Although there was theoretical talk about alternating current, no one had been able to determine how to make it work. Tesla’s heroic feat in transmitting electricity from Niagara Falls to Buffalo City, using alternating current, resulted in him being the first to send electricity to people’s homes. This achievement was widely covered in the press, and Tesla, at 39 years of age, was praised as a hero around the world.

While some consider Tesla’s alternating current induction motor as one of the ten greatest discoveries of all time (Tesla Society 2011), his genius was also demonstrated in the invention of the Tesla coil, which is widely used, even today, in radios and television sets and in other electronic equipment and wireless communication.

A scientist of vision, Tesla conceived of the virtually instantaneous transmission of wireless energy—energy that was free, convenient, and hazard-free—to all the corners of the planet. Knowing that the wireless transmission of power over long distances would result in significant losses of electrical power, Tesla conceived of the idea of transmitting electrical energy through the ground, instead of through the air. By experimenting, Tesla found that the ground, if it were charged highly enough, could become a conductor of electricity, potentially allowing the entire planet to be transformed into a transmitter of electrical energy. This type of extraordinary ingenuity was realized in his registration of over 700 patents, worldwide, and his contribution to the invention of radio technology was duly recognized by the United

[7] See Cheney, 1981; Cheney and Uth, 1999; Johnston, 1983; Jonnes, 2003; Lomas, 2000; O’Neil, 1992; Seifer, 1998; Tesla, 1982).

States Supreme Court in 1943, the year of Tesla's death, rendering Marconi's most important patent invalid.

Vision, to be translated into action, must be accompanied with perseverance and will-power. For six decades, from when he arrived in the United States in 1884 until his death, Tesla unrelentingly pursued his adolescent dream of wireless electrical power transmission through alternating current, despite discouraging hindrances and undesirable circumstances. Not only was he forced to dig ditches for two years, after Edison failed to keep his word to pay Tesla the promised $50,000 for his work on improving DC motors, but Edison also waged a war against Tesla's idea of alternating current. Even the complete loss of his New York laboratory in a mysterious fire, in 1895, did not cause Tesla to give up his dream.

Alongside his personal character traits, his conceptual ability—the ability to visualize diagrams, working out the details in his mind—also played a role in Tesla's ultimate success, as demonstrated in his solving the inherent problem in direct-current motors. In this instance, he visualized two coils positioned at right angles, supplied with alternating current 90 degrees out of phase, causing a rotating magnetic field and thereby inducing the AC motor. His conception of all forms of energy being cyclical in nature led him to defend alternating current.

3.3 Extremes of Reality and Experience

Extremes in the physical world, whether personal or material, have romantic appeal. Tesla manifested several such qualities: acute visual and auditory sensitivity, the ability to work unceasingly without sleep for up to three days and nights, and a remarkable memory, that made it possible for him to recall all of the details of the laboratory contents and records after the fateful fire that followed right after his success at Niagara Falls. In one sense, even physically enduring two years of ditch-digging and the associated psychological suffering—the humiliating lot of the immigrant—can be considered an extreme experience.

On another level, an extreme of reality may consist of setting a record or achieving the unusual. One of Tesla's most impressive records is the generation of a 130-footlong lightning strike. In generating electricity, being able to pump millions of volts into the earth's surface may be regarded as an extreme achievement.

3.4 A Sense of Wonder

Undeniably, even today Tesla's experiments and accomplishments evoke a sense of wonder as they did in his day, astonishing the world with the demonstrated marvels of alternating-current electricity at the World Exposition in Chicago in 1893, in one illustration sending sparks into the audience, harmlessly. It was only two years later that he transmitted electrical power from Niagara Falls to Buffalo City, turning a dream into reality. In 1899, he demonstrated another amazing experiment in wireless electrical energy transmission in Colorado Springs by lighting planted, unwired light bulbs at the touch of his hand. By pumping electricity into the earth's surface (about 100 million Volts), he was able to light 200 lamps from a distance of 25 miles without the use of any wires. It is also astounding that he—one of the greatest geniuses of his time—at age 87 years, died destitute and in obscurity, in a New York city hotel room that he shared with a flock of pigeons.

Finally, the Tesla story is, in and of itself, a story of wonder: his very nature, his immense accomplishments, his impact on the world. Books written about Tesla, such as *Tesla: Man Out of Time* (Cheney 1981) and *The Man Who Invented the Twentieth Century: Nikola Tesla, Forgotten Genius of Electricity* (Lomas 2000), bear witness to his remarkable heroic qualities and character.

3.5 Contesting of Traditional Ideas

Tesla, like other scientists of the past, had to struggle against tradition. Already as a student, he frequently enraged his professors by questioning the technological status quo. As he began his scientific experiments, he rejected the idea of direct current as the sole means of delivering electrical energy. Later, in the United States, after he had left the Edison Company, he, literally, rebelled against Thomas Edison, himself, who had set out on a name-smearing campaign against Tesla. Using alternating current, Edison conducted demonstrations of electrocuting animals in an attempt to show how unsafe that type of current was. Despite direct current then being the accepted technology, one in which the Edison Company had a huge investment, Tesla contested the prevailing practice and dismissed partisan considerations in struggling to establish his idea of alternating current and its benefits to society.

4 The Empirical Study

Bringing the Tesla story into the classroom in order to teach the concept of alternating current electricity cannot, by itself, guarantee either the improvement of conceptual understanding or the development of romantic understanding. An empirical study is required to evaluate the efficacy of the approach. What follows is a description of the study that was undertaken—its purpose, design, participants, and results.

4.1 Purpose

The purpose of this study was to investigate the effect of the Tesla story on students' understanding of the concept of alternating current. Three research questions were asked: (a) Does teaching through the Tesla story, that is, a story with all the characteristics of romantic understanding, encourage more engagement with science, in comparison with direct instruction? (b) Is teaching through the Tesla story more effective in helping students learn specific science content, in comparison with direct instruction? (c) Do students who are taught through the Tesla story develop a romantic understanding of the science content?

4.2 Research Design

A quasi-experimental research study was designed and conducted to answer the research questions.[8] The preference of this type of design over a genuinely experimental one is justified on the grounds that randomly assigning students to groups was impractical and undesirable. Random assignment to two different groups would have been difficult because of limited facilities and available time. Certainly, with random assignment, the possibility of student interaction during the study would be reduced and the average characteristics of the groups would tend to be more homogeneous. The first of these potential concerns was ameliorated by having the students of the first ten schools located in one area of the city form the experimental group and having the students from the other nine schools located in another area of the city form the control group. It was reasoned that through geographical isolation possible interactions of the control group with the experimental group would be removed as a factor, this being a greater concern than the interactions of students within the same classroom, which might, in fact, be desirable. Because of the uniform demographic characteristics of the available subjects, the lack of homogeneity was not an issue, as will be seen in the next section.

Even though it would be possible to assess the development of romantic understanding using a one-group design, it was considered essential to use two groups in order to detect any differences in the learning of science content knowledge between the groups exposed to two different teaching methods: one using the Tesla story (the experimental group) and the other using the Mastery Teaching Model[9] (the control group), which, in the experience of the researchers, is a well-trusted, direct-instruction method.

Some science content knowledge, such as alternating current (i.e., its production and transmission), cannot be taught and learned easily; therefore, teacher-centered instruction was used with both groups. It was reasoned that direct instruction (the control-group teaching method) bore more similarities to instruction through storytelling (the experimental method) than, for example, to inquiry (or hands-on)

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[8] See Cohen et al. 2000; Drew et al. 2008; McMillan 2004.

[9] More information on the Mastery Teaching Model is provided in Section 4.4.

instruction, in that these both involved the explicit presentation of a form of knowledge (through exposition or explication and narration, respectively) and both are purportedly effective in helping students learn specific content knowledge (Orlich et al. 2001; Stefanich and Hadzigeorgiou 2001).

4.3 Study Participants and Selection of Data

The participants[10] in the study were 197 Grade 9 students from 19 private preparatory schools in the wider metropolitan area of a southeastern European city. The age of the students was between 14 and 16 years, with an average of 15.25 years. The schools that participated offered the same courses as regular public schools. Their main objective was to prepare students for the public-school system, and, consequently, some courses were remedial. Similarly, the main expectation of the students was a good preparation for the public-school system and improved grades. All participants, according to their academic record, were average or below-average students. They all came from middle- and upper-middle class families and, with the exception of two students, they were all of the same nationality. With some confidence, it can be said that there was no significant variation in their socio-cultural background.

The criterion of the students' selection was only that the science teacher and at least half of the class were willing to participate in the project, thereby ensuring that a large enough sample would be represented at each school. Naturally, the teachers in most of the schools wanted as many students as possible to benefit from the intervention.

The first step in the selection process was giving all students the choice of participating in the study, which, they were informed, would involve an additional one-hour class every Saturday morning for the following two-and-one-half months. They were also told that this class was not a part of their regular coursework. The self-selected students of the first 10 schools formed the first treatment—or experimental—group, and the self-selected students of the remaining nine schools formed the second treatment—or control—group.

The rationale for using Grade 9 students, despite the concept of alternating current normally not being taught at that level, was that students at this age were expected to understand the world romantically. Their possible lack of knowledge of the prerequisite fundamental concepts of current electricity (the concepts of electric current, voltage, resistance, Ohm's law, Joule's law, electrical energy, and power) was addressed by having the teachers teach these fundamental concepts during the first four weeks of the study and then test the students twice on this material, once in the fifth week and again in the sixth week in order to insure concept retention.

For pedagogical and ethical reasons, students in either group who did not perform acceptably on the tests were still allowed to participate in the entire intervention, insofar that they would do what the whole class did (i.e., listen to a story, write in journals, take a test); however, the researchers did not take into consideration the responses or test scores of these students for the purpose of data analysis. No student was told about the data-selection process or that their responses and scores would be excluded from the data analysis. Teachers surreptitiously identified the selected students and the respective data. Consequently, the utilized data were comprised of results from the 197 students who demonstrated acceptable knowledge of the fundamentals of direct current electricity.

4.4 Procedure

Before the study began, all of the participating teachers attended four one-hour meetings at one of two schools in order to learn about the teaching method that each would be using, either about the storytelling-teaching or the mastery-teaching method. In the first school, the ten teachers were introduced to the concepts of teaching through storytelling and romantic understanding, based mainly on Egan's (1990, 1997, 2005a) work. These sessions emphasized that teaching science romantically is about presenting the

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[10] "Participants" are not all who were present in the teaching interventions but only those whose assessments were actually included in the data analysis, as elaborated, below.

Table 1 Time Frame and Research Activities for the Experimental and Control Groups

Week	Targeted Group	Activity
1, 2, 3 4	all students	Teaching fundamentals of direct current electricity (current, voltage, Ohm's law, Joule's law, electric power)
5, 6	all students	Assessment of students' understanding of fundamentals
7, 8, 9	control group	Teaching intervention: fundamental ideas about AC
7, 8, 9	experimental group	Teaching intervention: Tesla story
10, 18	all students	Assessment of students' understanding of AC

humanized, contextualized content so as to make students aware of it and, generally, employed the insights expressed in section 2 of this paper. In the second school, the remaining nine teachers were introduced to the Mastery Teaching Model (Stefanich and Hadzigeorgiou 2001). This model uses a seven-step teaching sequence: (1) focus of interest, (2) statement of learning objective, (3) instructional input, (4) monitor and adjust, (5) guided practice, (6) independent practice, and (7) evaluation. The first two of the four meetings were devoted to the presentation of the two teaching methods by the researchers, while at the third and fourth meetings, teachers created implementation plans and materials for the designated methods. Particular attention was paid to how the mastery-teaching sequence would be implemented for the specific science content during the study in order to ensure a minimum variability in the teaching of the content by the different teachers. This was thought imperative, given that in the storytelling group the issue of variability would be minimized by providing teachers with the Tesla story script that they would tell their students.

The classroom study was conducted over a ten-week period, concluding with a content-knowledge post-test that was re-administered eight weeks later to check for long-term retention of knowledge. The fundamental prerequisite knowledge of DC electricity was taught to all students during the first four weeks with testing in the following two weeks (see Table 1). The following three weeks consisted of instruction by two different modes: direct instruction for the control group and indirect instruction with the use of the Tesla story for the experimental group. The time frame of the study with the corresponding activities, not including the initial meetings with the teachers involved, is shown in Table 1.

The specific science content to be taught through either method to both groups of students was as follows: (1) the concept of alternating-current, (2) its production (process and apparatus used), (3) its advantages in transmitting electrical energy over long distances, (4) its transmission (process and apparatus used), and (5) the idea of wireless transmission of electrical energy. This content, which was taught explicitly to the control group, was also explicitly embedded in the script of the story at the appropriate points.

4.4.1 Writing the Tesla Story

The Tesla story was written by the first author, along with a participating physics teacher who had read all of the material provided by the author. The story was analyzed by the third author, an expert in the analysis of the literary story form, to insure the quality and fidelity of the story. No changes to the presentation script of the story were deemed necessary.

The beginning of the story details Tesla's background, his passion for alternating current, and his dream to come to America in order to harness the power of Niagara Falls for the purpose of transmitting electricity for domestic use. The main plot of the story includes his life and work in the United States. Emphases are placed on the dispute between Tesla and the Thomas Edison Company, his defense of alternating current and his production of it, and his remarkable feat of successfully transmitting electricity from Niagara Falls to Buffalo.

4.4.2 The Intervention

The essential distinguishing feature of the research study was the teaching intervention using the Tesla story. All the schools in the experimental group used the same story script, told from memory by the respective teacher without straying from the text. The teachers encouraged students to form mental images of both the events of the story and the ideas concerning science content during the narration. The story was told in two parts during two successive Saturdays. The third Saturday session was devoted to a discussion of the major events of the Tesla story with a repetition of the highlights. The science content embedded in the story, as presented during the first and the second sessions, was also part of that discussion. Nothing else transpired during those three Saturday sessions, except for some students commenting at the end of each session about Tesla, himself, and his work on AC electricity. The teachers recorded these comments in their personal journals as documentation of the possible effect of the Tesla story.

The schools in the control group all taught the same science content, which teachers all delivered with the same teaching strategy, namely, the seven-step mastery teaching sequence. They endeavoured to keep the levels of motivation high through the use of challenging questions, interesting connections, and appealing visual material. The time devoted to the teaching intervention was three one-hour sessions, spread over three consecutive Saturdays, equal to that used for the Tesla story by the experimental group. The first two sessions were devoted to the teaching of science content. The concept of alternating current and its production (process and apparatus used) was taught during the first session, while the advantages of alternating current in transmitting electrical energy over long distances, its transmission (process and apparatus used), and the idea of wireless transmission of electrical energy were presented during the second session. The third session was used to review taught material, answer questions, and provide additional guided and independent practice on the concepts.

4.4.3 Assessment of Learning and the Development of Romantic Understanding

Engagement, knowledge and understanding, skill (e.g., self-directed inquiry), and attitude development (e.g., curiosity and wonder) were the broad targets for assessing student learning. Both groups were assessed by the same three methods: (a) observations, during formal class discussions and informal discussions outside the classroom, which were recorded by the individual teachers in their personal journals; (b) traditional written (paper-and-pencil) tests, administered one week and eight weeks after the teaching intervention; and (c) analyses, both quantitative and qualitative, of students' journal entries. Student engagement with science was measured primarily through students' informal comments and their journal entries (the number of entries per journal and the number of comments and questions in the entries); the students' science content knowledge and understanding was measured primarily by their performance on the written tests; and romantic understanding was assessed through a qualitative content analysis of journal entries.

Instructions to the students in regards to keeping their journal were that the journal should consist of a plain notebook, be anonymous, specify the gender of the student, and should be a dated record of questions and comments about their learning experiences. Comments could be any length, from a single sentence to several paragraphs. For analysis purposes, any meaningful sentence or paragraph in the journals that referred to a fact, an event, or an idea in relation to students' learning experiences was considered. The journals for both groups were collected four weeks after the end of the intervention, giving the students more time to reflect and generate questions and comments.

The five characteristics of romantic understanding served as the categories for content analysis of the journals. Since these categories had already been established and elaborated, they did not have to be checked for their validity and reliability. In the analysis, the steps in conceptual analysis of the data (examining relationships among concepts) were followed (Neuendorf 2002; Weber 1990). The unit for the analysis was the paragraph, with any single-sentence entry being treated as a paragraph. Reliability was ensured by having two experienced qualitative researchers, who did not otherwise participate in the study, check the coding of the identified features of romantic understanding.

The learning of content knowledge about alternating current was assessed with a written test consisting of 10 open-ended questions, all of equal value. The score on any question was one mark or zero, and the maximum grade overall was 10. The knowledge and understanding assessed was distributed among the questions in the following sequence: the concept of alternating current (1–3), the production of alternating current (4–5), the process of transmitting electrical power over long distances (6–8), and wireless transmission of electrical energy (9–10). Students were judged to have an adequate understanding of a concept if they gave an acceptable response to all test questions within a specified grouping; for example, all three questions on the concept of alternating current had to be answered satisfactorily for the student's understanding of that concept to be deemed adequate.

The test, initially devised by the researchers, was studied for its validity by two professors of physics, who recommended some modifications. The resulting test consisted of the following 10 questions:

1. What is AC electricity?
2. Draw a graph showing a DC and an AC electrical signal.
3. What do we need to describe an AC signal?
4. How can we produce AC electricity?
5. How do a generator and a motor work?
6. Why is AC more efficient to transmit electrical power over long distances?
7. Explain what we can do to an AC signal if we want to transmit power.
8. Describe the process and the apparatus (technology) used for AC transmission and the mathematics we need in order to describe them.
9. What is the wireless transmission of electricity?
10. What are its advantages?

4.5 Results

The results from both the quantitative and qualitative data are discussed from the perspective of the three research questions.

4.5.1 Research Question 1: Does teaching through the Tesla story, that is, a story with all the characteristics of romantic understanding, encourage more engagement with science, in comparison with direct instruction?

A quantitative analysis of students' journals consisted of the total number of dated journal entries, the total number of comments (with multiple comments per entry possible), and the total number of questions contained in the entries. Tables 2 and 3 reveal that all counts for the experimental group were significantly greater than for the control group. Of the 95 students in the experimental group, 91 (96%) made journal entries, whereas only 56 of 102 (55%) in the control group did so. The most dramatic difference was demonstrated among the female participants in the experimental and control groups with 95% making entries as compared to 25%, corresponding to 148 entries as compared to 31, respectively. It is also noteworthy that many students in the experimental group continued to write in their journals up to four weeks after the Tesla story intervention, whereas most of the students of the control group stopped writing in their journals one week after the intervention. This suggests that the students of the experimental group were motivated to give additional thought to the story and write their comments and that they sustained their interest, which is evidence of deeper involvement on their part. Interestingly, not only did many of the entries made by the students of the experimental group relate to Tesla's life and work and not the science content, per se, but those of the control group did not display any curiosity about

Table 2 Journal Entries of the Experimental Group*

	Whole Class (N = 95)	Males (N = 55)	Females (N = 40)
Number of students who made entries	91 (96%)	53 (96%)	38 (95%)
Total number of entries	275	127	148
Total number of questions asked	293	162	131
Total number of comments	482	190	292

Table 3 Journal Entries of the Control Group*

	Whole Class (N = 102)	Males (N = 58)	Females (N = 44)
Number of students who made entries	56 (55%)	45 (78%)	11 (25%)
Total number of entries	105	84	31
Total number of questions asked	98	78	20
Total number of comments	177	136	41

* Entries contained both comments and questions, and these were counted discretely.

the origin or originator of the concepts, which accentuates the emotional response to the romantic elements of the Tesla story by the experimental group.

Evidence of student engagement can also be drawn from the teachers' journals. Teachers in the experimental group recorded that whenever an event from the Tesla story captured students' attention, they exhibited excitement and enthusiasm in their faces, along with exclamations and short comments which broke the otherwise complete silence during the narration of the story. Teachers also recorded that through informal conversations just before or after class they had learned that some students had done additional reading while at home (which was also recorded in some journals). Some students also used the internet to find more information about Tesla's life and work. This is a noteworthy finding, as it characterizes listening and responding to the Tesla story as a transformative experience, since listening to the story made a difference in the students' daily experience.[11] The finding is more remarkable in light of the fact that no teacher who taught the control group recorded anything similar and no student from that group wrote anything about additional reading outside of class. Although informal comments and even students' journal writing concerning their activity must be taken with some reservation, this evidence is likely reliable because students did not receive any grade for writing or commenting, they gave up their free time to attend Saturday classes, and their participation was voluntary.

The student and teacher journals provide compelling evidence to answer Research Question 1 in the affirmative—there is remarkably greater engagement on the part of the group who heard the Tesla story as compared to the group who received direct instruction employing the Mastery Teaching Model.

4.5.2 Research Question 2: Is teaching through the Tesla story more effective in helping students learn specific science content, in comparison with direct instruction?

A comparison of the means of students' scores on the 10-item test on alternating current yields a statistically significant difference on both post-tests—one week and eight weeks after the intervention—for the two groups (see Table 4), with the experimental group outscoring the control group. Given that the test questions explicitly asked students about the content that was presented to them through both teaching approaches, one might have expected the control group to have had an advantage over the

[11] See Pugh (2004) for a discussion of transformative experience.

Table 4 Means and T-Test Values of Student Scores on a 10-item Test on Alternating Current

Group	N	M		SD		t	
Experimental	95	8.80	6.45*	1.22	1.78*	7.64	10.40*
Control	102	6.76	4.02*	1.83	0.90*		

P < 0.01, df1 = 94, df2 = 101

* Delayed post-test

Table 5 Successful Responses to Test Questions on Four Targeted Ideas

Idea	Experimental Group (N = 95)		Control Group (N = 102)	
	1st test	2nd test	1st test	2nd test
	n (%)		n (%)	
Concept of AC	68 (72%)	67 (71%)	42 (41%)	31 (31%)
Production of AC	53 (56%)	48 (51%)	37 (36%)	28 (27%)
Transmission of AC electrical power	65 (68%)	58 (61%)	30 (29%)	22 (22%)
Wireless transmission of electrical power	72 (76%)	70 (74%)	39 (38%)	18 (18%)

storytelling group. After all, the control group, through the seven-step sequence of the mastery-teaching model, had focused entirely on content knowledge, with guided and independent practice as part of the instructional sequence providing an additional opportunity for content learning. The corresponding focus on science concepts in their journal entries did not translate into better performance on the concept test, as indicated in Table 4. The written post-tests, however, provide evidence of better performance on the part of the storytelling group (see Table 5). Furthermore, considering that all students’ academic ability was very similar (the vast majority of students attending the schools from which the sample was drawn are average or below average), the performance of the experimental group in comparison to the control group is significant. The data bear witness to the effectiveness of the storytelling intervention in science teaching.

A t-test for independent samples is a valid statistical test considering the normality of test-score distribution of both groups (with approximately 70% of the scores falling within one standard deviation above and below the mean) and the samples sizes of about 100. Every other measure (quantitative or qualitative) was consistent with the conclusions drawn from a comparison of the test scores, supporting the conclusion that the experimental group learned and retained the specific science content on AC electricity significantly more fully than the control group.

4.5.3 Research Question 3: Do students who are taught through the Tesla story develop a romantic understanding of the science content?

A content analysis of the student journals of the experimental group provides evidence that many of them developed a romantic understanding. The characteristics of romantic understanding that were identified and the number of occurrences of those features in their journals are reported in Tables 6, 7, and 8. At least two romantic characteristics were identified in all journals (see Table 6), with wonder and heroic elements (see Table 7) occurring most frequently. Interestingly, wonder was often coupled with other characteristics, resulting in its appearing in the highest frequency of all romantic characteristics. In the analysis, for example, when a heroic quality or an extreme was identified in a paragraph together with a sense of wonder, each characteristic was counted separately. This aspect of the analysis yields the observation that heroic elements and a sense of wonder were ubiquitous in the journals. While this result

Table 6 Number of Romantic Characteristics in Student Journals of the Experimental Group

Number of Romantic Characteristics	Number of Students
2	12
3	18
4	35
5	30

Table 7 Romantic Characteristics in Student Journals of the Experimental Group and Frequency of Appearance

Romantic Characteristics	Number of Students	Frequency of Appearance
Humanization of Meaning	43 (26M, 17F)	106 (55M, 51F)
Heroic Elements	94 (53M, 41F)	221 (157M, 164F)
Wonder	94 (54M, 40F)	258 (131M, 127F)
Extremes of Reality	50 (32M, 18F)	72 (52M, 20F)
Contesting of Ideas	26 (17M, 9F)	55 (36M, 19F)

Table 8 Romantic Characteristics Explicitly Associated with Science Content Knowledge and Frequency of Appearance in Student Journals of the Experimental Group

Romantic Characteristics	Number of Students	Frequency of Appearance
Humanization of Meaning	28 (19M, 9F)	77 (44M, 33F)
Heroic Elements	66 (31M, 35F)	105 (70M, 35F)
Wonder	68 (37M, 31F)	113 (62M, 51F)
Extremes of Reality	34 (24M, 20F)	54 (29M, 25F)
Contesting of Ideas	10 (6M, 4F)	19 (13M, 6F)

may seem an inevitable outcome of the plot of the story, these elements emerged quite naturally from the students' writing even when they did not make any reference to any of the other elements.

Since most of the students' comments in their journals[12] were about Tesla' s life and work, the characteristics of romantic understanding appeared more frequently in that context than in the context of science content (see Tables 7 and 8). Still, 2/3 of the students gave comments that had an association with content knowledge. The number of students whose journal entries associate romantic elements with science content and the frequency of appearance of those romantic elements provides evidence of romantic understanding being associated with content knowledge (see Table 8). Furthermore, the teaching episodes integrated the context and content as a coherent whole, and even though some students did not demonstrate making any explicit romantic associations with the science content knowledge in their journals, the fact that they performed as well on the factual test as those who demonstrated a romantic understanding of the science content makes it likely that they developed such an understanding.

4.6 Discussion

4.6.1 Limitations

While the research project yielded indisputably positive results, studies with a two-group quasi-experimental design have inherent potential limitations, as was the case in this study. The first is the

[12] Sample comments are presented in the Appendix, and the reader is encouraged to examine these, as they reveal extraordinary insights and observations.

absence of random assignment, the effects of which were largely ameliorated through careful design, described in Section 4.2. Second, although we tested the students for background knowledge of the fundamentals of direct current electricity before starting the teaching of AC, we did not pretest them for existing knowledge on alternating current. Nevertheless, based on our experience with students at this level and of this demographic, we are confident that they did not have such prior knowledge. Any such knowledge, even if present, would not have favored one group over the other, as the students were from two suburbs of the same city and under the jurisdiction of the same national curriculum. Any design limitations would tend to be insignificant in comparison with the significant effects of the research intervention, leading to a larger degree of confidence in our conclusions.

A factor often considered as a confounding variable in experimental studies is "history" (i.e., the effect of events outside of the study between the two post-tests) because it is outside the control of the study, and, therefore, has a negative effect on the internal validity of the design (McMillan, 2004; Drew, Hardman, Hosp, 2008). Apparently motivated by the Tesla story, some of the students (43% of the sample) spent time outside school researching Tesla and his work, as indicated informally and in their journals. Although this outside-of-class research could have had an effect on the students' knowledge and understanding of the content presented to them through the Tesla story, thus undermining the validity of the quasi-experimental design, their research involved mainly the events of Tesla's life story and not content knowledge, (i.e., content of the test). Even with a small likelihood that "history" played a role in the second post-test, the fact remains that the experimental group performed statistically better not only on the second test but on the first post-test, too, before any outside-of-class learning could have affected their performance. That their superior performance on both tests is likely due to the inclusion of the story and the manner in which it was designed and delivered is, therefore, more compelling.

We have postulated that the positive results of the intervention were due to the development of romantic understanding. The possibility that the novel and innovative nature of the experimental approach, by itself, may have been a motivating factor for the students (i.e., the Hawthorne effect) must, nonetheless, be considered. This novelty, however, was not limited to the experimental group, as the control group also received treatment that was unusual—a novel curriculum in an extra-curricular setting—but with a less positive effect.

Another possible explanation for the positive effect of the story intervention is that by providing context the Tesla story caused students to focus their attention on the introduced ideas and the phenomenon of study. This explanation correlates with research findings that confirm that "when information is emotionally charged, we are more likely to pay attention to it, continue to think about it over a period of time, and repeatedly elaborate on it" (Ormrod 1999, p. 420), and stories provide such opportunities for emotional stimulation. This focusing effect is compatible with the development of romantic understanding and may simply serve to enhance its effect.

The activation of narrative understanding, by itself, may also have contributed significantly to the observed effect (see, for example, Avraamidou and Osborne 2009; Hadzigeorgiou and Stefanich 2001; Milne 1998). As was already discussed in Section 2 of this paper, narrative understanding is integral to and inextricable from romantic understanding; consequently, we do not see this as detracting from our assumption that romantic understanding played a leading role. It may, indeed, be impossible to separate the influence of storytelling and the resulting narrative understanding from the effect of romantic understanding. If that is the case, then this inextricable association may only add weight to the already proven benefit of including romantically crafted stories to improve learning in science education. It may, indeed, be impossible to strip good science stories of their romantic qualities by virtue of them having significant and dramatic discoveries and inventions at the heart of their plot.

4.6.2 Implications

The intervention with the experimental group, based upon a romantic teaching framework, can be considered successful in that it encouraged emotional involvement with science and facilitated learning. This learning was likely enabled and promoted by romantic understanding. Yet, the data of the study do not show that the teaching intervention with the control group was, necessarily, unsuccessful. In the *individual* case where a student from the control group answered all test items successfully and made thoughtful journal entries, one cannot claim the superiority of the storytelling approach over the mastery-teaching approach, and one cannot say that romantic understanding led to a better comprehension of the science content. One can say, though, that students who performed well in either approach learned the science content but that their thinking and understanding were different. Promoting and legitimizing individual differences in thinking and understanding is an important aim of science education since it can encourage involvement with science, which, in turn, may lead to a transformative experience.

In discussing the heroic element in relation to the Tesla story, one could surmise that promoting science learning through the stories of lone "heroes" might make students think that only special people are capable of doing noteworthy science and, thereby, alienate them from such heroes. In the light of our earlier discussion of the association with heroic qualities as a cognitive tool of romantic understanding (see Sections 2.1.2 and 2.3.2), it is apparent that the student, alone, chooses to hold Tesla up as a hero and that no one can impose such admiration of an individual on the student. Data from student journal entries in Table 6 reveal that, together with the element of wonder, the heroic element was expressed by the most students. Moreover, empirical evidence from students' journals (see Appendix) reveals explicitly that the specific human qualities of the hero inspired their science learning. Comments such as "I wish I could read and work like Tesla" and "This is really admirable and we should all do like him if we want to help the world" indicate the students' desire to emulate admirable human qualities. In this case, we can also say that students were inspired through their romantic understanding. The speculation that the students' exposure to "lone heroes" would serve as a discouragement to their enthrallment with science was not observed in our study. Regarding interest in the heroic, it is noteworthy that the only category in which the number of girls responding was greater than the number of boys was in that of heroic qualities as related to science-content knowledge (see Table 8). Generally, students' comments provide evidence that they were impressed and inspired by Tesla's accomplishments and considered him worthy of emulation as an exceptional human being with superhuman mental and physical abilities (see the Appendix for more examples of journal entries).

The composite data suggest that the storytelling approach enriched instruction in such a way that it stimulated the imagination and the curiosity of the students in respect to Tesla's character and his accomplishments. This effect is reflected in such comments as the following one:

> That Tesla lit 200 or 300 lamps without wires is really astonishing. He sent the electric current through the ground without using any wires. Perhaps we can use it to send electricity to islands without using cables in the sea. I am curious whether islands receive electricity without wires.

This phenomenon, by virtue of the absence of the story, would not have happened in the control group in this way since the students would not, for example, have been aware of Tesla's accomplishment of lighting several hundred lamps by transmitting AC through the ground. Without the injection of the story, even the impetus for independent research is lacking, attested to by the nature of the journal entries of the control group which, as already mentioned, were devoid of any curiosity about the origin or originator of alternating current and of any indication of their reading on the topic outside of class. It is apparent that the outcomes for the two groups are fundamentally different. In examining the students' journals, one observes that there is a strong connection between romantic understanding and the students formulating their own creative ideas.

For those who would argue the impracticality of storytelling in science instruction on the basis of additional time required for such an inclusion, it should be noted that the variable of instructional time in this study was constant for both groups.

5 Conclusions

The research study presented in this paper focused on the use of a specific type of storytelling in science instruction, based on the assumption that a romantic understanding is a requisite of its successful application in the classroom. The delineated features of romantic understanding were illustrated in the historical Tesla story, as found in the literature. The story of Tesla used in the study was deliberately fashioned to embed these features in the plot, along with the respective science concepts of alternating current electricity. The results of this quasi-experimental study (based on an analysis of students' journals and the same post-test written at two different times), despite any of its limitations, provide evidence of the importance of encouraging romantic understanding in science at this age level.

In comparison with a group of students who were taught the idea of alternating current (its production and transmission) explicitly by means of the Mastery Teaching Model, the students who, through storytelling, were encouraged to understand this concept romantically became more engaged with the content and the context of the story, as demonstrated through the quantitative and content analysis of their journal entries. Some of these students also demonstrated imagination and curiosity in their journal entries, which was not observed in the control group. Additionally, they undertook relevant independent research on their own initiative, which was indicative of the transformative effect of the storytelling instruction. This is a notable difference from the students in the control group who did not undertake any related reading outside of class, according to the analyses of the teachers' observations. The results pertaining to the experimental group are encouraging for further research into the role of storytelling and also into the role of the romantic framework in the learning process. While our conclusions are based on the content of AC electricity in the context of the Tesla story, we believe that they are generalizable to this age group, provided that the story has significant science content and embeds all of the cognitive tools that nurture a romantic understanding.

As supported by the data presented earlier, teaching through the Tesla story was more effective in helping students learn the science content than teaching with the direct-instruction method. Despite the control group, that had been taught with a content-centered approach, having possible advantages, such as the explicit science-content questions and additional opportunity for and reinforcement of content learning, the approach did not translate into better performance on the concept test. Instead, the students in the storytelling group outperformed the control group on the written post-tests, attesting to the greater effectiveness of this method over the direct-instruction method.

The findings of the research study affirm that the storytelling instructional approach with the Tesla story resulted in students developing a romantic understanding of the science content and not simply of the narrative content. Many comments made in the student journals revealed strong connections between Tesla's life and work—the romantic element—and science-content knowledge. These comments were marked by admiration for the scientist and curiosity about the science in the story.

It is clear that the development of romantic understanding through the Tesla story, with its specialized features, contributed to the students' motivation to learn. The fact that some students in this group performed additional work outside of school and, as a group, performed significantly better than the control group, attests to its motivating stimulus. While other contributing factors are not, necessarily, ruled out, the story with its inherent cognitive tools appears to be the dominant factor in the development of romantic understanding.

It is both likely and unproblematic to assert that the innovative nature of the storytelling approach, the concurrent use of narrative understanding, and the romantic nature of the Tesla story, itself, all played a role in generating positive effects and that these components are inseparable from romantic teaching and developing a romantic understanding. The theoretical considerations and the design of the experimental intervention corresponded exceptionally well to what would have been expected in student responses, and it is unlikely that another approach not designed in this way, that is, without the integration of the romantic elements, would have a similar effect.

The implication of this study for science education is that a particular type of a science story, that is, a romantic story, has significant potential for improving learning in the discipline. Such a story should be based upon human qualities, heroic or otherwise, that evoke wonder and give students the opportunity, through the plot, to associate science content with such qualities and simultaneously experience a sense of wonder. These qualities give students the opportunity to become aware of the human dimension of science, which, as Milne (1998) pointed out, should be given priority when selecting and structuring a science story.

In the light of recent studies and a growing body of literature around teaching science using aesthetics, and specifically the Deweyan notion of "aesthetic experience" (Girod 2007; Pugh 2004), one may point out an important implication for science-education research, namely, the study of the effect of romantic understanding on out-of-school experience. Such studies could possibly provide useful information to answer the question about the extent to which romantic understanding can also be a transformative kind of understanding.

Appendix: Samples of Students' Comments as Evidence of Romantic Characteristics

Humanization of Meaning

- It is unbelievable that behind the invention of the alternating current there was such an effort by a man who suffered a lot because of what happened to him. He lost his job, he became a digger, his laboratory caught fire.
- The war between Edison and Tesla is something that I did not know but now I can understand that Tesla's dream and hope are responsible for his victory and for what we all have today because of alternating current.
- Tesla's unbelievable work and passion are the two factors that can explain how alternating current won direct current.
- I liked that Tesla had the dream to send electricity to all people on Earth free. But people wanted to make money and that is why his dream was not realized. I think the fire in his lab after the great triumph at the Niagara Falls was not something that just happened. People who did not want Tesla's dream come true tried to stop him from realizing his dream. Money, money is everywhere.

Heroic Qualities

- Tesla is an admirable man because he wanted to do good to the world. He left his country and worked for another country, wanting to help all people. This is something really admirable and we should all do like him if we want to help the world.
- I wish I could read and work like Tesla. I really think he is someone special. It is amazing that he could work non-stop for several days. I think he is very special not because he worked all those hours but because he solved the problems he was working on.
- The idea to use a transformer to increase the voltage and decrease the electric current is amazingly clever and shows Tesla's intelligence. As an idea it is not so difficult. If you want less losses you need less current so you must find a way to decrease it. But simple things require intelligence. And imagination. And Tesla had a lot of them.
- Transmitting electrical energy to several km from Niagara Falls by using electric cables was a big thing. But to transmit electrical energy through the ground and to avoid the use of cables was really excellent and shows Tesla's power of mind.

Sense of Wonder

- The idea of alternating current is a very revolutionary idea. But how did Tesla get it and why did he insist that it was better than the standard current? It is amazing that despite all the problems he faced, he remained faithful to his purpose.
- That we can produce alternating current by using loops of wire moving or rotating inside magnets is very simple indeed. This idea of loop is very useful idea. In the transformer making loops of wire and changing the number of loops in the two coils can increase or decrease the electric current. It is just so clever idea. Simple and very clever. Wow!!

- The transformation of alternating current is something astonishing. I have been thinking about it a lot. Very very clever. I think Tesla had understood that direct current cannot be transformed, so that's why he insisted on alternating current.
- I am truly amazed by Tesla who fixed the lighting system in a city, in France, by not using a single drawing. He did everything by working it out in his imagination. How did he do this? This is really impressive.
- That Tesla lit 200 or 300 lamps without wires is really astonishing. He sent the electric current through the ground without using any wires. Perhaps we can use it to send electricity to islands without using cables in the sea. I am curious whether islands receive electricity without wires.

Contesting of Conventional Ideas

- I like the fact that Tesla made his university professors angry. Perhaps if he did not go against what those old professors knew about electricity there would not have been progress in using alternating current instead of regular current.
- That Tesla did not listen to what his father was saying to him about becoming a priest must have made a big difference in the world as we know it today. I think it all started when Tesla followed his own ideas and feelings.
- Tesla went against the Company of Ericson [sic] despite the fact that he was alone and without money. But he won. He taught us a lesson: he who insists wins even when he has to go against problems and difficulties.
- I was thinking that the light we have at home and that all the electrical appliances work because of what Tesla did one century ago. The electric current we use today has a history behind which is the disagreement between Tesla and Edison. If Tesla had agreed with Edison who knows if we had electricity in our homes.
- Tesla was a very peculiar person. He went against everything. His father, his teachers, and the American system. But he succeeded. I think people who disagree with the system can be successful. But you need guts. It is not easy. Many times I want to disagree with my father and my teacher but in the end I agree with them.

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