Using Nikola Tesla's Story and his Experiments as Presented in the Film The Prestige to Promote Scientific Inquiry: A Report of an Action Research Project

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ABSTRACT: This paper reports on an action research project undertaken with the primary aim of investigating the extent to which situations that evoke a sense of wonder can promote scientific inquiry. Given the intense interest, curiosity and wonder that some students had begun to develop after seeing the film *The Prestige*, a science teacher used this film, which showed Tesla's demonstrations on the wireless transmission of electrical power, as a source of curiosity and wonder. The class that participated in this action research project was an 11^{th} grade class in a rural area of southern Greece. Through an analysis of students' journals, but also through observation, informal discussions, and paper-and-pencil tests, it was found that students (a) became involved with Tesla's life and work thus developing an interest in current electricity, (b) learned about the skin effect, the biological effects of AC and DC currents, and (c) better understood Ohm's law in their attempt to find out how much current can cause serious damage or even kill a person. Moreover, some students did begin to develop scepticism and open-mindedness, in addition to their sense of wonder. The paper also presents a planning framework for teaching the Tesla story.

KEYWORDS: Tesla, The Prestige, sense of wonder, scientific inquiry, action research.

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Introduction

The importance of inquiry as a teaching-learning model is quite indisputable. Inquiry learning is considered effective, since observation, questioning, predicting, hypothesizing and drawing conclusions – all part of the process of inquiry – require students to move beyond rote memorization and become independent thinkers and problem solvers (Stefanich & Hadzigeorgiou, 2001). Moreover inquiry learning results in better retention of ideas (Renzulli, Gentry, & Reis, 2004). In the context of science education it is considered crucial that students understand that science is not just a collection of concepts and principles and a catalogue of facts, but also a process. It is considered crucial even for those in the early grades, who need to understand that science is not only about factual knowledge but also about a way to arrive at such knowledge. It is for this reason that great emphasis has been placed on teaching science as inquiry (Bass, Contant, & Carin, 2009; Stefanich & Hadzigeorgiou, 2001; Martin, 2003). Although scientific inquiry is a complex process, central to this process is the posing of questions about the natural phenomena and the attempt to find answers to such questions (NRC, 1996, p. 214). Given though the problem of engaging students in school science (Hadzigeorgiou, 2008), the question one is tempted to ask is how the process of asking questions can be initiated and sustained.

Fostering students' curiosity and their sense of wonder can no doubt encourage the posing of questions. But how could one foster curiosity and wonder? Novel, inexplicable, unusual, unexpected situations, phenomena and ideas that make students feel surprised and astonished can all be potential sources of curiosity and wonder. Elsewhere I have explored the distinction between curiosity and wonder and the crucial role of both for science education (Hadzigeorgiou, 2006, see also Opdal, 2001), but for the purpose of the present action research project it suffices to consider that both encourage students to ask questions. What is at issue, however, is not whether students become curious and develop a sense of wonder, but whether their curiosity and wonder initiate scientific inquiry. For it should be stressed that surprise and astonishment, even bewildered curiosity, do not necessarily lead a student to both ask a question and pursue an investigation in order to answer it. In other words, a "wow" exclamation, even a "why" question, do not guarantee self-directed inquiry.

It is the purpose of this paper to report on an action research project that was undertaken with the main purpose of investigating the extent to which novel, unusual, inexplicable, and unexpected situations and phenomena can promote scientific inquiry.

Rationale for the Action Research Project

Generally, student engagement in science is quite problematic (Hadzigeorgiou, 1997, 1999, 2008; see also Pugh, 2004). In the context of Greek education, this is very true even for students who study science, since they focus primarily on their entry into the university, thus leaving almost no room for studying anything else, even related science topics. On the other hand, there is evidence that among those who study science, physics is not a popular subject. Students appear to prefer biology and environmental issues (Williams, Stanisstreet, Spall, Boyes, & Dickson, 2003) or they think that it is not important to them personally (Jenkinks & Nelson, 2006). Yet physics may be the subject that has the potential to foster a sense of wonder in students, and thus help initiate inquiry.

An opportunity to test such a hypothesis was found when an 11th grade teacher realized that some of his students, who had seen the film *The Prestige*, had developed an intense interest in, and a great sense of wonder about, the experiments (along with the physics that could explain those experiments) presented in that film. The film was about two turn-of-the-century London stage-magicians, who competed for fame and fortune, but it also showed Tesla's experiments in Colorado Springs regarding the wireless transmission of electrical energy. Tesla, while in Colorado Springs, had been approached by one of those two magicians and asked to help him create the best stage act ever. Although this act fell within the domain of science fiction, Tesla's demonstrations and experiments on wireless transmission were astonishing and perplexing, and helped raise a number of questions, some of which fell within the curriculum content of grade 11 physics. More specifically, those demonstrations were about unwired light bulbs that lit at the touch of Tesla's hand, light bulbs planted in the ground that could also light, and Tesla himself who could walk through sparks totally unharmed.

So the teacher's idea was to become involved in action research with the following research questions:

- Does a sense of wonder (at and about the aforementioned demonstrations) initiate and promote scientific inquiry?
- What form does such inquiry take?
- What do students actually learn?

Context and Methods

The class that participated in this action research project was an 11th grade class in a rural area of southern Greece, consisting of 15 males and 13 females. Collaboration between the science teacher and me became possible through email communication on a weekly basis during the implementation of the project. It all started when a couple of students, who had seen the film *The Prestige*, were excited in talking about the film, and more specifically about the demonstrations/experiments, which were performed during the film.

Since Ohm's law and electromagnetism were their curriculum content, the teacher asked the whole class whether they would like to see the film while at school. *The Prestige* was shown in the classroom. The class agreed and after they watched the film the teacher explained that if some students would like to do some independent research in order to answer some questions raised by Tesla's demonstrations. They could take a week and then they could discuss their findings in the classroom. He also asked students to keep an optional journal, in which they could write the questions they wanted to answer and make entries of things they considered important (i.e., important facts, impressive ideas, what they think they learned during their investigation). No name was to appear on any journal, except for the letters M or F, which would indicate a male or a female student.

The following week 17 students (11 males and 6 females), that is, 60% of the total number of students, reported that they had worked independently (and sometimes in collaboration) in order to find some answers to their questions after having watched the film at school. Those students asked for more time, one more week they said, to do more research, in order to answer their questions. The teacher agreed, and next week there was a discussion concerning students' questions, which had guided their inquiry. This discussion was also followed by students' "mini-presentations" regarding the findings of their independent research.

Student engagement in scientific inquiry was assessed through an analysis of students' journals, which became the primary research instrument. An assessment of student learning (i.e., knowledge and understanding, as well as skill and attitude development) was made through observation (during both class discussions and informal discussions outside the classroom), through traditional paper and pencil tests (administered two weeks and the other six weeks after the students watched the film) and through an analysis of students' journal entries.

It is important to stress that teacher intervention was minimal. Guidance was provided right after the showing of the film in the classroom and then on an individual or group basis during the subsequent two weeks in order to provide more focus on what students were supposed to investigate (i.e., the teacher suggested that the human body is a conductor so an application of Ohm's law can be something that they can investigate in connection with their questions, the difference between the human body and a copper wire in their behavior when electric current flows through them).

Results

In regard to the first research question, the film did initiate self-directed inquiry. More than 50% of the classroom became involved in the project. More specifically, one week after the film was shown in the classroom, 19 students became engaged in a discussion regarding three initial questions that came up after students watched the film in the classroom. Of those 19 students, 17 (that is, 60% of the total number of students) reported that they had worked independently (and sometimes in collaboration) in order to find some answers to their questions. All 17 students had made journal entries regarding questions raised by the film and other comments.

Students' most frequent initial questions after watching the film were the following:

- Were Tesla's experiments/demonstrations real?
- How can they be explained?
- Can they be replicated?
- How can Tesla walk through sparks?
- How safe is it really to "play" with electric current?

Students' most frequent questions after their initial inquiry during the first week were the following:

- Which is safer for humans, DC or AC current?
- How much current can kill a person?
- Can science do tricks?
- Who was Nikola Tesla?
- Why has Tesla been marginalized by history and science textbooks?
- Why are Edison's and Marconi's names more well known than Tesla's?
- Why hasn't Tesla been given credit for his inventions?

In regard to the second research question, students' inquiry took the form of question posing, which led them to a search in order to find answers to their questions. These questions referred to Tesla's experiments and the physics behind them as well as Tesla's life and work. Students' primary inquiry tool was the worldwide web, since their purpose was to get information on Tesla's life and work, and since experiments were very difficult, dangerous or impossible to do. The availability of, and quite easy access to, information, as one student wrote in his journal, "makes one pose more and more questions, which, sooner or later, will find an answer".

In regard to what students learned as a result of engaging in the project, except factual knowledge concerning Tesla's life experiences, especially the war of the currents (that is, the controversy between Tesla and Edison), they also developed understanding of the concepts of voltage, current and electrical resistance. Moreover they became familiar with the idea of AC current and the skin effect. In trying to answer questions about how much current can kill a person, students became interested in safety values concerning the electric current passing through the human boy, in the idea of human electricity, and also in the fact of the variability of the electrical resistance of the human skin.

Seven students did report in their journal that they understood Ohm's law better, since they applied it to many situations. Three of those students also wrote in their journal that they were impressed by the fact that the electrical resistance of the human skin can vary considerably, depending on its condition (i.e., sweaty, carrying bruises), and they developed an extra interest in applying the law and working out the value of the electric current in order to find out whether that value was above or below an established safety level.

Two tests, one administered two weeks and the other six weeks after the students watched the film, did provide evidence that Ohm's law was understood, since students could apply it to a wide variety of situations, without confusing the units of the physical quantities involved in the mathematical equation involving that law. Out of those 17 students, who made journal entries, 12 did perform well on the delayed test, in comparison with the 14 students who did well on the first test. It is interesting to note that 10 of those students had not performed well on a pretest that had been administered right after the teaching of Ohm's law, which was well before students had watched the film.

From their comments in the journal, and from the discussion that took place in the classroom after the students watched the film, it appears that both open-mindedness and skepticism were also two attitudes that some students began to develop. Tesla's life experiences, led several students to be skeptical about the fact that

Tesla is not as well known as Edison and Marconi, although Tesla appeared to deserve credit for several ideas, especially that of AC current, and their application to a wide variety of fields. At the same though they also became skeptical about whether Tesla's abilities were indeed of such caliber. That they should be open to ideas and never believe what "stories about people" are around was also commented by two female students. One of them wrote in her journal:

> Tesla must have been an incredible person. Otherwise why should a film portray him in the first place? Also what his biography says is truly impressive and inspiring. But are all these facts about his life true facts? I do not think I can make up my mind until after I read more about him. Also I think I need to read more about what those who appear as Tesla's rivals or enemies have to say about those things concerning his life. Was Edison so immoral and bad as he appears to be? […] If Tesla had all those wonderful ideas about transmitting electricity to all places on the Earth, then who held him back? I think there is more to learn in connection with this thing.

A "cognitive struggle" also experienced by a male student is quite apparent in the following comment:

> The more I read about Tesla the more I respect him. The more I read about his life and about his way of thinking (for example the idea of the Earth as a huge battery with one pole on the ground and the other one in the ionosphere) the more I become impressed. But are all these facts about Tesla's life and work in America true? I really admire Tesla and his work but I also have a little doubt about what he did.

It deserves to be pointed out that students' skepticism was tied to the notion of truth, which did come up in the comments of several students, who asked about whether Tesla's demonstrations were real. Three students, in fact, in their attempt to answer that question, began searching the web in order to find out whether the demonstrations shown in the film could be historically documented. Two of those students, despite the evidence found (i.e., Tesla's experiments were indeed performed), were not inclined to believe in the truthfulness of those demonstrations. For those two students, unless "live experiments" were performed (same as or similar to those performed by Tesla), everything was considered science fiction.

The Tesla story also helped students offer an explanation as to why Tesla was marginalized by history. Two students, a male and a female, in their attempt to provide an answer, an explanation, to the fact that Tesla was placed in the margin of the academic world, offered a moral that fits, in their view, the Tesla story. More specifically the female student wrote: "Never pour scorn on scientific ideas however strange or even crazy they may seem and sound at first". She thought it was because Tesla's ideas sounded crazy that he was not fully accepted by the academic community. And the male student put down the following: "One should never try to make a career outside the academic world and the security it offers, and should be very careful when co-operating with businessmen in order to secure funding".

In regard to what impressed students most, an analysis of their journal entries gave the following facts and ideas as the most impressive:

- Tesla's imaginative vision to transform the entire planet into a colossal electrical transmitter, so that energy could reach the most distant places on the planet.
- Tesla's imaginative vision of the Earth as a huge battery with one pole on the ground and the other one in the ionosphere.
- Tesla's ability to work out solutions to problems and do drawings of his inventions without the aid of paper and pencil.
- Through Tesla's theatrical flair, science became magic that kept audiences spellbound.
- Tesla's ingenuity as a troubleshooter while working for Thomas Edison.
- The idea of wireless transmission of electrical power.
- The fact that the electrical resistance of the human body depends on so many factors (i.e., being sweaty or dry, having bruises, metal rings, touching a power-line with one or two hands)
- One of the pioneers of radio, who also built the first AC power system that resulted in changing the face of the whole world, Tesla's contribution to science has been marginalized by history.

Discussion

The first thing that deserves some space for discussion is that student engagement with Tesla's story and his demonstrations concerning the wireless transmission of energy was high. The high number of students who became involved with the project, although this was not part of their compulsory curriculum and although no any bonus (extra grade) was promised by the teacher, does show that the film did have an effect on students motivation to search for some answers to their questions. This motivation, as the students' questions revealed, was due to their surprise and astonishment, which derived both from Tesla's demonstrations and from his life experiences. However, their surprise --and this is quite interesting --did not stop in the classroom, where they watched the film. It became a motive that led them to search for answers, while at home, during the following two weeks.

The present action research project does provide empirical evidence that justifies the Aristotelian view that a sense of wonder is the source of all intellectual inquiry (Toulmin, 1976). What one can draw from this project is that students' motivation did not derive simply from their curiosity and their sense of wonder about the electrical phenomena and Tesla's life events, but from their awareness that their knowledge was incomplete, and that some phenomena can exist at all. In other words, what initiated and sustained student inquiry for at least two weeks were not simply some unusual natural phenomena regarding electricity or some strange and mysterious events in Tesla's life, but, to use Maxine Greene's phrasing, a "shock of awareness" that students received. As Greene (1978) has pointed out "a great part of our everyday life is not lived consciously, and since nothing makes an impression, the world seems bland, muffled, and vague" (p. 185). It is for this reason that people need "exceptional moments, moments of response to 'shocks of awareness'" (p. 185). Tesla's demonstration regarding wireless transmission of electrical energy and his own life events and experiences did provide students with a "shock of awareness". Students already had some fundamental knowledge of electricity, but Tesla's demonstrations did make them aware that their knowledge was incomplete.

It should be pointed out here that the present project does provide evidence that justifies Edmund Burke's (1990) argument that although "the first and simplest emotion we discover in human mind is curiosity" (p. 11), it is the state of astonishment, during which "all emotions are suspended and the mind is so entirely filled with its object that it cannot entertain any other" (p. 53). Indeed students were so taken by Tesla's demonstrations, that their attention was focused on those demonstrations as their object of study. The project also provides evidence that we should distinguish between participating in a learning activity and becoming involved with the object of study (Hadzigeorgiou, 2008).

What should be also said is that although students' inquiry did not involve any experiments, through which they could test some of their ideas, and although scientific skills such as those of observation, prediction, hypothesis formation and testing were not developed, the process of asking questions --a central feature of inquiry--was promoted to the greatest extend. Moreover the Tesla story, as was unveiled to the students through their own investigation, did inspire some students to study science, while some others thought that science can be a fascinating subject. More specifically:

- Tesla inspired five male students to pursue work (through further inquiry) on electricity during the summer or their free time.
- Tesla inspired three students – two male and one female - to pursue a university degree in science or electrical engineering.
- Three male students became interested in science fiction.
- Two female students thought that science can be really fascinating.
- One female student though that biographies can enrich the teaching and learning of science.

The involvement of female students is quite noticeable. Given, of course, the empirical evidence, which supports the view that learning science is not simply a matter of acquiring or constructing knowledge but also a matter of deciding what kind of persons students are and what they aspire to be, and that those who make the choice to study science are those who resolve to be scientists from an early age (see Hadzigeorgiou, 2008), the relationship between science learning and personal identity raises one crucial question: Is science learning a possibility only for those who envision, for some reason, a career in science and engineering? The involvement of two female students, who upon questioning did not envision a career in science or in a science-related field, does not answer this question in the affirmative.

On the other hand, the fact that some students thought to pursue work on electricity during their free time, especially in the summer, or even a university degree in science or electrical engineering, provides evidence that involvement with the object of study can have an effect on students' career choice. Given that those three 11th graders (two males and one female), who thought to pursue a university degree in science or electrical engineering, were one year away from their career options, their comments do have some weight and were not made just to fill a page of their journal.

Although those three students' comments provide evidence that the humanization of content knowledge (i.e., the human context of the AC story and Tesla's story in general) played a significant role in inspiring them, the role of scientific facts and ideas in this process of inspiration cannot be disputed. For example, Tesla's greatest invention – the "magnifying transformer", which was a 180-foot metal tower (antenna) built over a huge Tesla coil, on the outskirts of Colorado Springs, that was used to pump 10 million volts into the earth's surface, and the result was the most powerful man-made electrical surge ever made, was commented by two of those three students. Also the ideas of transforming the entire planet into a colossal electrical transmitter (so that energy could reach the most distant places on the planet), or that of the Earth as a huge battery with one pole on the ground and the other one in the ionosphere were found "astonishing" and "impressive" by those two students. One can therefore infer that these ideas must have played a role in inspiring them and in making them think to choose a career in science or engineering. The power of scientific ideas to inspire students and even contribute to identity-building had been remarked upon by Richard Feynman (1964) and more recently by some science educators (Hadzigeorgiou, 2005b; Wong, Pugh, and the Dewey Ideas Group at Michigan State University, 2001).

The fact that two male students began to see things differently after their involvement with the project is also quite noteworthy. As one student wrote in his journal, "The more I search for information in order to get some answers to my questions the more I realize that physics is very different from what I used to think". The other student commented that "Ohm's law has now a different meaning for me [. . .] never thought that what we learned last month in class could have had a relationship to those magical demonstrations that Tesla performed". The comment "From the moment I watched that film I saw electricity 'with a different eye'", made by a female student, also adds to the role that Tesla's demonstrations, his life events and experiences, followed by students' inquiry, played in changing those students' outlook on electricity, as their object of study. This change of outlook is crucial in education (Hadzigeorgiou, 2005a), given that a number of philosophers and educators have stressed the view that learning should be directly related to a change of outlook, to the ability to perceive the world in a non-habitual way (Hirst, 1972, p. 401; Jardine, Clifford & Friesen, 2003, p. 102; Peters, 1967, p. 9; Schank, 2004, p. 37).

If students' interest in school science and their sense of wonder about physical phenomena and ideas are considered crucial factors in the context of science education (Millar & Osborne, 1998; see also Goodwin, 2001; Silverman, 1989), then the present action research project provides science educators and teachers with some food for thought. Both Tesla's astonishing and impressive demonstrations and the human context in which his experiments and life events took place played a catalytic role in developing students' interest in electricity, as their object of study, and also in fostering a sense of wonder at and about Tesla and his work. The question (as was raised by a male student in his journal and as was discussed in the classroom) about "whether Tesla's vision of transmitting energy through the earth, even to the most distant places on the planet, could provide an answer to our energy problem", although not answered in the end, did help evoke in the whole class a sense of wonder about the possibility of applying such an idea. It was that wonderful idea of using the entire planet to transmit energy and Tesla's imaginative thinking (the very source of that idea) that fostered students' sense of wonder. Perhaps Witz's (1996) argument about wonder playing a crucial role in the development of a "deep-based" relation to and respect for science, and therefore a role in one's worldview, is not so unrealistic. Therefore science educators and science teachers might concur with Witz (1996) that wonder should be given the highest place in science education, and be regarded "a feature and a goal of science education itself" (p. 603).

It is important to note at this point that students' motivation and their involvement with the project led us to develop a planning framework for the Tesla story. We thought that the Tesla story could be used in the classroom when teaching 11th or 12th grade physics, with some modifications, depending on the grade level and the actual curricular content. So we focused on the following general components, which our story needs to have:

- *Central ideas to evoke a sense of wonder*: a) One of the pioneers of radio, who also built the first AC power system that resulted in changing the face of the whole world, Tesla's contribution to science has been marginalized by history. b) Tesla's imaginative vision to transform the entire planet into a colossal electrical transmitter so that energy could reach the most distant places on the planet. c) Through Tesla's theatrical flair, science became magic that kept audiences spellbound.
- *Human values*: ingenuity, imaginativeness, insistence, persistence, curiosity, patience, commitment.
- *Protagonists*: Nikola Tesla and Thomas Alva Edison. Also featuring Guglielmo Marconi.
- *Mental images*: a) Tesla, bedridden for months after contracting a very powerful form of cholera, pleading with his father and saying: 'Perhaps I will recover if you let me be an electrical engineer'; b) Tesla walking in a park with some

friends, becoming entranced with the sight of a beautiful sunset, having a vision of a vortex whirling eternally in the sun, and blurting out 'See my motor here. . . watch me reverse it' c) Tesla working nonstop for two or three days and nights in his New York laboratory until he solved the mysteries of electricity' d) Tesla's commitment, while working as a ditch digger and suffering all the indignities of the immigrants of his time (circa 1880), to the idea of AC polyphase current, and his insistence to attract the attention of new financial supporters. e) The happiness on Tesla's face when he discovered that high frequency currents were harmless for the human body. f) The happiness on Tesla's face when he was successful at generating electricity at Niagara Falls and sending AC power to Buffalo 20 miles away.

- *Plot of the story*: (a) Tesla's strong desire to live and work on AC current and his humanitarian purpose to supply free energy to all people made him immigrate to America. (b) The conflict and scientific/business debate between Tesla and Edison over the safety and effective transmission/utility of DC and AC currents. b) The significant discovery (reinvention) by Tesla of AC current in the form polyphase current.
- *Ideas to be learned by the pupils*: 1. Physics Content: a) The idea of AC current, b) the advantages of AC current when it comes to transmitting power to long distances, c) the physiological effects of DC and AC currents, d) the idea of wireless transmission of energy, e) skin effect 2. Nature of Science: a) Science is a social activity: the ideas put forward by one scientist open new ways for other scientists, scientists think further what other scientists have thought before them, b) science is a human endeavor (i.e., it is tied to the scientists' struggle, to their ambitions, anxieties, frustrations, hopes), c) the accidental nature of scientific discovery, d) the difficulties scientists experience sometimes in understanding what other scientists are saying, e) the existence of conflict in the scientific community.
- *Moral*: a) Never pour scorn on scientific ideas however strange or even crazy they may seem and sound at first. b) Trying to make a career outside the academic world and the security it offers, and attempting to co-operate with businessmen are not considered, at least historically, appropriate ways to do science.

Summary and Conclusion

The pedagogical value of the project was that involvement with the project was high, even for female students, who have been considered as "outsiders" (Brickhouse, 1994, 2003), and that some students were really inspired by Tesla's demonstrations and also by Tesla himself. Inspiration, as I have elsewhere explored, is an important notion to consider in the context of science education (Hadzigeorgiou, 2005), but what should be stressed here is that the film, particularly Tesla's demonstrations and Tesla himself, played a catalytic role in promoting inquiry in a general sense. Curiosity and a sense of wonder as well as attitudes, such as open-mindedness and skepticism, were developed. Students also learned about the skin effect, the biological effects of electric current, and better understood Ohm's law in their attempt to find out how much current can cause serious damage or even kill a person. As for the battle between Edison and Tesla concerning the relative safety of AC and DC currents, students understood that economic considerations played a principal role, and that physics, especially its applications, can never be value free and objective as they used to think. This change of students' outlook on physics (documented also through other comments as was previously mentioned) can perhaps serve as the best justification of the overall educational value of the present action research project. For as the educational philosopher R.S. Peters remarked, "To be educated is not to have arrived at a destination; it is to travel with a different view" (Peters, 1973, p. 20). The Tesla story did indeed provide students with an opportunity to travel, at least some 'curricular distance', with a different view.

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