Science & Education (2007) 16:335–352
DOI 10.1007/s11191-006-9026-x

The Application of Historical Narrative in Science Learning: The Atlantic Cable Story

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Abstract The use of historically based stories to teach science has both theoretical and practical support. This paper outlines how the historically based story may be utilized effectively in the classroom and, as an illustration of this, presents the story of Lord Kelvin's role in the laying of the first trans-Atlantic communications cable during the period from 1857 to 1866. Expected and observed classroom benefits that accrue from this approach are summarized. The paper concludes with an outline of a program of research which incorporates the development of historically based stories.

1. Introduction

The discovery of a good historically based story is like the discovery of a hidden treasure. Perhaps the fascination arises from the romance of far-removed events with participants who had the same kinds of hopes, dreams, and struggles as we, and yet, in a very different environment. Good teachers often employ such stories in their teaching. They have found, like Swiss science educator Fritz Kubli, that 'bare bones do not make an appetizing meal' for students (Kubli 2005, p. 520). Historically based stories (sometimes called 'cases') are a valuable, some would say essential, part of providing a rich and diversely connected context for student learning.

One such story is that of the laying of the first trans-Atlantic communications cable during the period from 1857 to 1866, with emphasis on the role of Lord Kelvin. While the Atlantic cable story qualifies as one of the great episodes in the history of science and technology, to the best of my knowledge, this story has never been published in the form of an historical case for use by science teachers and students. Yet, as Matthews (1994) points out, '[i]mportant episodes in the history of science and culture ... should be familiar to all students' (p. 50). Of relevance in the presentation of such a story is the advice of Monk and Osborne (1997) that

> [t]o comprehend the importance and significance of scientific ideas, it is essential to have some insight into the social context, the dominant forms of thinking, the numerous blind alleys of pursuit, and the difficulties of persuading others of the validity of any new theoretical interpretations. (p. 409)

This paper includes a discussion of the issues involved in the designing and use of historically based stories, the historical case in the form in which it has been used in the classroom, and a description of expected and observed classroom benefits that accrue from the approach. It concludes with an outline of a program of research of which includes the development of historically based stories.

2. What Can the Historical Science Story Achieve?

There is good evidence that in order to engender meaningful learning, it is essential that teaching and learning methods be imbedded in appropriate contexts (Kenealy 1989; Martin and Brouwer 1991; Roth and Roychoudhury 1993). Historical contexts address the 'why' and 'how' aspects of the development of science and technology in a way that includes the scientists as living, breathing persons who are concerned with personal, ethical, sociological, and political issues. It is generally accepted that this form of presentation is likely to engender increased motivation in students. Such historical materials must not consist of mere chronologies, but rather expose the settings in which discoveries were made in the form of narratives and stories (Stinner et al. 2003). The use of stories to teach science has both theoretical and evidential support apart from the contextual argument (Egan 1986, 1989; Miall and Kuiken 1994; Helstrand and Ott 1995; Kubli 2005; Norris et al. 2005). It is the literary story form, in particular, that is known to produce consistent affective engagement (Miall and Kuiken 1994). Narrative techniques in the literary story 'accentuate... activity in cortical areas specialized for affect' (Miall and Kuiken 1994, p. 392). Teachers hope to capitalize on affective arousal in the form of increased student motivation.

Beyond motivational effects, the story should raise compelling questions or leave the student with unresolved problems. These questions arise not only from the story itself, but from the scientific issues and science concepts that the story contains. The identification of questions or problems as central to the purpose of the story is in agreement with the views of Gil-Pérez (2002), who see the generation of questions as an essential element of the constructivist approach to teaching and view of learning. In their words, '[f]rom a scientific point of view it is essential to associate knowledge construction with problems: as Bachelard (1938) stresses "all knowledge is the answer to a question" ' (p. 566). Student questions are essential to the model of *student as novice researcher*, which is implicit in the approach of this paper.

3. How should History be Incorporated in the Story?

It is essential that history of science be incorporated into the story in a manner that does justice to original sources and sound historical interpretation. Although poetic license is a part of writing any story, even a historically based one, imaginary details must be consistent with the historical record. History must be placed in its original context while relating it to our current views in a manner that respects the originators and portrays them in a fair and balanced way. The objective of accuracy or faithfulness to the historical record must, in turn, be balanced against the demands of a curriculum that limit the depth to which the history can be probed. It should be realized that the place of history is not only to make a conceptual point but also to introduce the humanistic element into the process of learning science. Portraying scientists as human beings, thereby giving students the opportunity to become affectively involved in the *story* of science is a worthy goal in itself. Reading and researching history of science yields an abundant supply of interesting stories that relate in a meaningful way to the science that students study.

4. How Can the Story Incorporation Process be Modelled?

Like Kubli (2005), I view the story as a 'door-opener' to the study of a scientific concept and as only one dimension (although an essential one) of a contextual approach to teaching. I argue elsewhere that an effective contextual approach contains at least five elements, namely, the (1) practical, (2) theoretical, (3) social, (4) historical, and (5) affective contexts (Klassen in press). These contexts, to the degree that they are present in a learning situation, interact with one another and cannot be considered in isolation. It is possible and, indeed, desirable for learning to take place in more than one context at a time.

The approach is summarized in a diagrammatic fashion in Figure 1 and is called the *Story-Driven Contextual Approach* or SDCA (Klassen in press). Students will bring their ideas, attitudes, prior knowledge, and experiences to the whole learning process and, if the experience is to be considered a success, they will leave with somewhat changed or new ideas, attitudes, knowledge, and skills.

The SDCA visualizes the learning process as beginning with the story. The main role of the story is to generate interest and raise important questions about the scientific subject matter of the story (Metz et al. in press). After hearing the story, students are encouraged to formulate a set of problems that come to mind, which they might address. Alternatively, the teacher might supply questions that are to form the basis for a student-group investigation (these could be both theoretical and experimental in

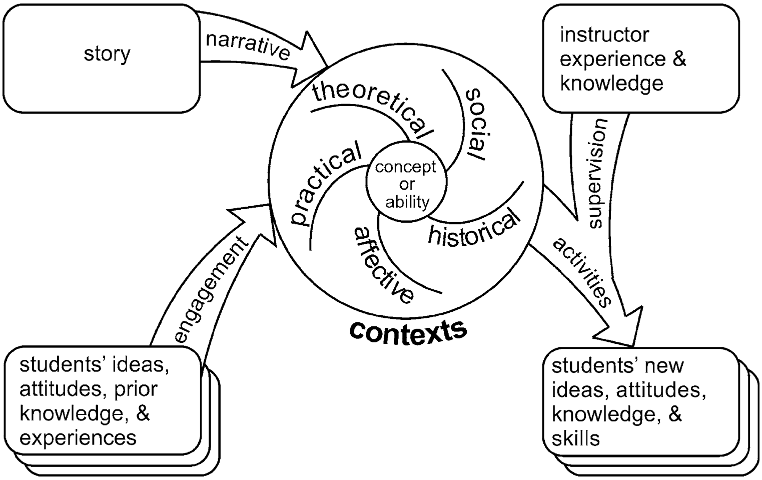


Figure 1. A Schema for the Story-Driven Contextual Approach.

nature). The supervisory role of the teacher is crucial in mediating between initial student concepts as elicited by the story and the target concepts of the instructional unit. Finally, the students will present a report on their investigations.

The SDCA is not the only model for incorporating history of science with teaching. The model of Monk and Osborne (1997) gives another perspective. In their model, the emphasis is on the process of teaching, and they begin with an activity that elicits the ideas of students. Elicitation is implicitly included with the SDCA in the form of the story (a 'door-opener'). Stories tend to leave certain aspects to the imagination and by this and other literary means raise questions and issues in the minds of the listeners. Creatively portrayed stories may also include illustrations ('demonstrations') with an historical flavour. Monk and Osborne emphasize experimental tests of questions and hypotheses and the discussion and evaluation of these activities by students and teacher. Experimental activities (the 'practical' context) are expected to be a part of the SDCA, and the evaluation of them will be a part of the preparation for the presentation of results. The main difference between Monk and Osborne's model and the SDCA is the prominence given to the story in the SDCA that is intended to help elicit students' preliminary ideas, stimulate the generation of questions and problems, and, generally, to enhance student motivation.

Some practical questions arise during the designing and teaching of an instructional unit that incorporates a science story. The reader might well ask whether a story should be told to the class or whether it is all the same if students read the story for themselves. Cognitive research using MRI has shown that there are significant differences in the way the brain processes read and told story-like sentences (Michael et al. 2001). Listened-to stories produce a significantly greater degree of semantic processing (Michael et al. 2001), which involves a heightening of expectations for what will come next in the story (McDonald and Brew 2001). Listeners generally respond to oral stories by attempting to determine the point of the story (Vipond and Hunt 1984) which results in the generation of a number of questions. The effectiveness of the oral story approach is also supported by research showing that learning is improved when students generate their own questions and, subsequently, also their own answers (Cox and Ram 1999). The raising of questions in the Atlantic Cable Story was part of the instructional process as it was initially conceived.

5. Lord Kelvin and the Atlantic Cable Story

The following story has been used on two occasions to teach various concepts in physics to a senior class of physics students at the University of Winnipeg. The entire historical case is contained on the website http://www.sci-ed.ca. The story was told to students as it appears below together with PowerPoint images of relevant photographs and illustrations without any accompanying captions. Commentary relating to the educational aspects of incorporating the story into science instruction is presented in italics to separate it from the story as it was told originally.

On August 17, 1858, intercontinental electronic communication officially began with a ninety-eight-word message from Queen Victoria to American president James Buchanan across the first Atlantic cable. The leading scientific figure in the cable-laying mission was the mathematical physicist Professor William Thomson, later to become Lord Kelvin. He worked with financiers, engineers, and ‘electricians’ (electrical technicians) to make the cable a reality. The laying of the first functioning Atlantic cable between 1857 and 1866 was made possible only through the solution of a wide range of scientific and technological problems. *Here the student is led to expect that scientific and technological problems will be raised in the story.*

The main scientific question surrounding the design and practicality of an Atlantic cable was conceived at a meeting of the British Association in London in 1854 in the form of a chance question asked of Kelvin after the presentations had been made. Kelvin recalls the incident:

> I was hurriedly leaving the meeting of the British Association, when a son of Sir William Hamilton, of Dublin, was introduced to me with an electrical question. I was obliged to run away to get a steamer by which I was bound to leave for Glasgow, and I introduced him to Professor Stokes, who took up the subject with a power, which is inevitable when a scientific question is submitted to him. He wrote to me on the subject soon after that time, and some correspondence between us passed, the result of which was that a little

> mathematical theory was worked out, which constituted, in fact, the basis of the theory of the working of the submarine cable. (Thomson 1890, p. 486)

Little did the thirty-year-old professor know that the problem would become an all-consuming one for him and that the he would have a major role in the laying of the first communications cable linking Britain and North America – a cable that was known for a time as the Eighth Wonder of the World (Kimmel and Foster 1866). *Interestingly, it seems to be a student question at the end of Kelvin's lecture that stimulated Kelvin's interest in the cable signal issue. Students at this level will already be familiar with Stokes' Law, and the handing over of the mathematical aspects to Stokes by Kelvin will likely not go unnoticed. Kelvin implies that the mathematical theory was required before he could begin work on the project. It certainly illustrates the close linkage of mathematics, physical theory, and technological development.*

Kelvin's direct involvement in the Atlantic cable venture began in 1856 when he met American tycoon Cyrus Field. Field had retired with a fortune at age 33 but re-entered the business world as a result of the Atlantic cable project having caught his imagination. It would probably not have been possible to complete the successful laying of a working Atlantic cable between 1857 and 1866 had it not been for this combination of genius. Field possessed future vision, eternal optimism, dogged persistence, and business prowess. Kelvin possessed an international reputation as a scientist, new insights into the physics of the cable, an unfailing dedication to the project, and an unwavering confidence in the answers supplied by science. Of the directors selected for the Atlantic Cable Company in 1856, Kelvin was the only scientist. By 1848, he had proposed the absolute (or Kelvin) scale of temperature. In 1855, he had published the first in a series of papers relating to cable telegraphy. That same year he was awarded his first patent for '[i]mprovements in electrical conductors for telegraphic communication' (Thompson 1910, p. 1275). The year that the Atlantic Cable Company was formed, he was awarded the Royal Medal of the Royal Society. In the light of these accomplishments and of their timing, it is not surprising that Kelvin was invited to become a member of the board of the Atlantic Cable Company. *Here, some of Kelvin's qualifications for undertaking the project are established for the student. In such a venture, however, mathematics, physical theory, and technological development must be joined by business prowess and high finance. These last two aspects are provided by Cyrus Field.*

However, before the venture began, several areas of study had to be developed, among them oceanography. Up to that point, the ocean floor had not been mapped, and, in anticipation of the Atlantic cable, methods of depth sounding had to be invented. Another key question that preoccupied scientists involved in the venture was signal retardation in a submarine cable of the length required in the distance of 2050 miles between Valentia Bay, Ireland and Trinity Bay, Newfoundland. Kelvin was already prepared with the electrical 'theory' that he had developed beforehand. In an 1857 letter to Helmholtz, he had written:

> I have worked a good deal ... at the solution of problems (exactly like those of Fourier) regarding the propagation of electricity through submarine wires. It is the most beautiful subject possible for mathematical analysis. No unsatisfactory approximations are required; and every practical detail ... gives a new problem with some interesting mathematical peculiarity. (Thompson 1910, pp. 336–337)

Faraday and Morse were convinced that the signal delay depended only on the capacitance of the cable, but Kelvin argued that the signal delay depended on the product of the cable resistance and capacitance or, in other words, on the square of the cable length, a statement that became known as Kelvin's 'doctrine of squares' (Dibner 1959). Kelvin's theoretical position was a scientific controversy. In 1855, the project electrician on the Atlantic cable, Mr. Whitehouse, had published a paper disputing Kelvin's conclusions based on measurements. The exchange between Kelvin and Whitehouse became a public debate. Kelvin argued, in his response, that Whitehouse had misinterpreted his own measurements. *Students are now alerted to the scientific disagreement that existed between Faraday and Morse, on the one hand and Kelvin on the other. That such disagreements do, indeed, exist points to the sometimes tenuous nature of the early developments in any scientific and technological field. For a more detailed discussion of this disagreement, the reader is referred to the relevant section below.*

When Kelvin joined the Atlantic cable venture, it was already too late for the cable design to be altered. Since he believed the cable resistance to be an important factor, he began testing sample pieces of the cable as it was manufactured. He found that among 45 samples he tested, the conductivity varied from 42 to 102% of the standard copper sample he used (Dibner 1959, p. 17). He maintained in his dealings with the Atlantic Cable Company that quality control measures be taken to insure the purity of the copper conductor. *The complexity of the situation heightens with the problem of the lack of quality control in manufacturing. Dealing with such a difficulty would require knowledge of the metallurgy of copper wire. An excellent resource on this topic is provided by Blake-Coleman's* (1992) *history of copper wire, and any interested students would benefit from reading the book.*

The process of the laying of the first fully successful Atlantic cable consisted of several short failed attempts and five major attempts, two of which were successful. Kelvin was aboard every voyage as an unpaid scientific consultant. These voyages were made from 1857 to 1866, with the American Civil War intervening between the third and fourth expeditions. The cable-laying missions began in 1857, with two ships, the *Agamemnon* and the *Niagara*, provided by the British and American governments, respectively. That year mission failures prevailed from August 5 to 11, until on August 11, when the ships were over 200 miles out, the cable broke due to the accidental misapplication of the cable brake that was used to keep the cable from paying-out in an uncontrolled fashion. There was no more time for another expedition that year due to the shortness of the storm-free period on the north Atlantic. *At this point in the story, the emphasis shifts to the sheer drama of the venture. Life-threatening dangers alternate with scientific and technological breakthroughs. The story oscillates between almost certain failure and exhilarating success. Students will almost certainly want to recount portions of the story from here on to their friends.*

By this time, Kelvin was aware of the great difficulty in measuring signals over wires of the length required, so, in order to improve signalling capability over the cable, Kelvin used the intervening months to invent a mirror galvanometer, which was called the marine galvanometer. The mirror reflected a beam of light originating from a lamp placed behind a slit on a measuring scale. The letters of the alphabet were transmitted as certain amounts of deflection on the scale or as positive and negative deflections to represent Morse code. The invention of the marine galvanometer was considered so significant at the time that physicist J. C. Maxwell was inspired to write several stanzas of poetry (a parody on Tennyson's 'Song III' from *The Princess*) which appeared in *Nature* in May of 1872. He wrote:

> The lamplight falls on blackened walls,
>
> And streams through narrow perforations;
>
> The long beam trails o'er pasteboard scales,
>
> With slow, decaying oscillations.
>
> Flow, current, flow! Set the quick light-spot flying!
>
> Flow, current, answer, lightspot! Flashing, quivering, dying.

A major difficulty plaguing the venture was the struggle to maintain the mechanical integrity of the cable. A restraining force had to be applied as the cable was released and the ship moved forward so that the immense weight of cable extending downward to the ocean floor did not cause the cable to pay-out uncontrolled and simply end up in coils on the ocean floor. The measures taken to keep this from happening had prematurely ended the attempts in the first year. In the intervening months, Kelvin not only constructed his mirror galvanometer, but worked out the dynamics equations for the cable, showing that it behaved like a limiting case of a catenary, making a perfectly straight line from the point of entry into the water to the ocean floor. The model allowed the developers to make more accurate tension calculations for the cable. *Fortunately, most students at this level will have sufficient mathematical background to understand the theory of the catenary. Students do not often have the opportunity to study problems of crucial importance by means of applying mathematical and physical theory, as the case is here.*

In 1858, the ships set sail again only to be met with a severe storm, the worst in living memory, in which the *Agamemnon*, carrying Kelvin, almost sank. Finally, on July 29 of that year, after a number of failures and false starts, the ships met in mid-Atlantic where the two segments of cable were spliced together and began laying the cable. (See the Appendix for an account, in the form of a literary story, of what happened aboard that voyage.)

It was soon found that the *Niagara*'s compass was reading incorrectly due to the large amount of iron in the sheath of the cable coiled in its holds. This caused the ship to veer off course badly. A pilot ship was sent in front of the *Niagara* to keep it on course. Communication along the cable was kept from ship to ship during the entire process, using Kelvin's marine galvanometer, to insure that the cable remained intact. On August 5, the ships reached their respective destination ports with their cables. For the first time in history, a telegraphic message was sent across the Atlantic, linking North America with Europe.

The announcement of the success met with weeks of jubilant public celebration across North America. Comparisons of this event were made to the discovery of America and the invention of printing. In the meantime, Kelvin had left the cable installation to pursue his regular duties. The electricians setting up communications under the direction of Whitehouse found that, contrary to Whitehouse's instructions, they needed to use Kelvin's marine galvanometer in order to detect signals. Whitehouse had his own detection system that he wished to use, but it did not work. He ordered the operators to fabricate signals on his own signal detection system manually and record them as if they had arrived across the cable. The fact that the cable was not a complete success was hidden from the public. The signals were detected with the mirror galvanometer using a candle as a light source. Three operators traced the beam reflection on a wall and made a majority guess as to the intended character that was being transmitted. During this time, the ongoing disagreement between Whitehouse and Kelvin came to a climax as Whitehouse insisted on increasing the signal strength from 600 to 2000 V, which resulted in the cable's insulation failing on September 18. After this fiasco, the Atlantic Telegraph Company dismissed Whitehouse. Soon the state of affairs of the communications was realized by the press, and on September 26 of that year the *New York*

Leader printed the question; ‘Have we a pack of asses among us and are they specially engaged in electrical experiments over the Atlantic cable?’ The newspaper question showed insight into the situation, since the developers were, in fact, using the installation process to develop the techniques needed.

Since the failure caused a financial loss of at least £ 500,000 for the investors, there was a great public outcry and the British Board of Trade, together with the Atlantic Cable Company, appointed a commission of inquiry into the matter, which deliberated from December 1, 1859 to September 4, 1860. The report issued was comprehensive and explicit in its recommendations for what should be done to insure success. After that, with substantial effort, Field was able to raise another £ 600,000 to attempt to install an improved Atlantic cable. The largest ship in the world at the time was the *Leviathan*, now idle, having failed financially. The ship weighed 19,000 tons (over 17 million kilograms) and was powered by an 11,500 horsepower steam engine (the equivalent of 75 average automobile engines). The company manufacturing the cable purchased the ship, renamed it the *Great Eastern*, and refitted it for the task at hand. The task of coiling the 2300 miles of cable into three holding tanks took from January to June of 1865. A crew of 500 was required to operate the ship, of which 200 were required merely to raise its anchor as it left port on July 23, 1865. This attempt to lay the cable was full of problems, and finally, on August 2 the cable broke after 1,186 miles had been laid. Numerous attempts to snag the cable and lift it off the ocean floor failed, and on August 11 the ship headed back to port.

Surprisingly, the level of optimism about the venture remained as high as ever. A new company, the Anglo-American Telegraph Company, had been formed, and it commissioned the manufacture of more new cable of greater tensile strength than that of the previous year. As the *Great Eastern* sailed from Ireland on July 13, 1866, it maintained communication with the shore via the new cable under the scientific direction of Kelvin. It arrived off the shore of Newfoundland on July 27. A signal was sent from Newfoundland to Ireland using a miniature homemade battery consisting of a copper gun cap, a tiny strip of zinc, and one drop of salt water. The initial speed of operation was eight words per minute and the cost of transmitting a message of twenty words or less was $100 U.S. in gold or $150 U.S. in banknotes.

As a result of his role in the laying of the Atlantic cable, Queen Victoria knighted Kelvin in 1866. Kelvin was justifiably honoured by British society. In 1892, 26 years later, Queen Victoria raised Sir William to the peerage, which is when he became Lord Kelvin. When he died in 1907, Kelvin was buried in Westminster Abbey, next to Sir Isaac Newton.

6. Questions Raised

Students with some physics and mathematics background easily comprehend both the practical and theoretical problems raised by the cable, and there are a significant number of such issues. Among the scientific problems raised are (1) the influence of material purity on the resistivity of copper, (2) the calculation of resistance of a wire, (3) the calculation of capacitance of a co-axial cable, (4) the nature of a signal in a simple capacitor-resistor circuit as a first approximation of a coaxial cable, (5) the theory of electrical signals in a long co-axial cable, (6) the density of seawater and buoyancy of the cable, and (7) the complex nature of the forces on a cable as it is being released into the ocean.

The effect of various impurities and of the manufacturing process, itself, on the resistivity of copper wire is a wide-ranging topic in metallurgy and solid state physics (Blake-Coleman 1992). Kelvin spent considerable effort in investigating the effect of impurities, including oxygen, on copper conductivity (Thomson 1860). Impurities, like iron, have a strong negative effect, while the presence of oxygen has a positive effect due to its scavenging action in forming oxides. The question of quality controls and their dependency on impurities during the manufacturing process was of great importance to the signalling capability, which, as Kelvin showed, depended partly on electrical resistance. The complexity of these scientific and technological issues can be an eye-opener to students, who are used to approaching concepts in an isolated and simplified fashion.

Calculation of the electrical resistance and capacitance of the first Atlantic cable is an exercise with results that tend to be surprising to students. In the first place, they must use the original specifications to construct a good model for their calculations. They then find that the resistance of the original 2050 mile length of cable was likely about 23 kilo-Ohms and its capacitance about 300 micro-Farads. Using their knowledge of elementary resistor-capacitor circuits, they can readily estimate that the wire time-constant must have been in the order of seven seconds. Discovering this fact about the original cable puts into perspective Kelvin's legitimate initial concerns about the viability of the cable and the critical nature of the debate over the dependency of signal retardation on the square of the cable length. Furthermore, Kelvin's derivation is readily comprehensible to intermediate university physics students in the somewhat simplified form published later by Bright (1898, pp. 528–531).

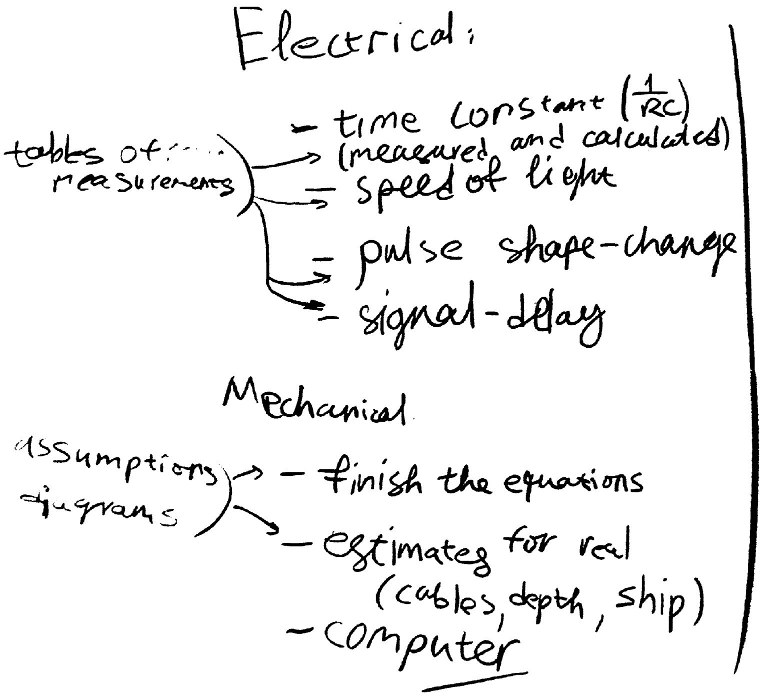
In my experience, most students have never considered how to explain signal delay in a resistive-capacitive circuit conceptually. The concept is not an intuitive one, as is illustrated by the disagreement between Kelvin, on the one hand, and Morse and Faraday, on the other. Faraday had come across the problem in 1854 when the engineer Latimer Clark asked him to make observations on a long cable coiled inside a water tank. That same year, Faraday published his qualitative explanation of the signal delay phenomenon he had observed. According to Faraday, the signal in the wire created an electrical disturbance from induced opposite charge in the water which, being at a lower electrical potential, took a longer time to assemble (Faraday 1854, p. 515). When Kelvin heard about Faraday's explanation in a letter from Stokes, he immediately worked out the problem, mathematically, for himself. He disagreed, fundamentally, with Faraday that the problem is purely one of electrostatic induction. Students will appreciate the disagreement over the issue, and it will help them begin to think about the concept behind a phenomenon that they have studied merely as a mathematical derivation, up to this point; however, they would benefit from the consideration of a simple resistor-capacitor circuit before they delve into the matter of the extended co-axial wire, as Kelvin did. The simple circuit may be understood by noting that due to Ohm's Law, the resistance hinders the rate of current flow that serves to charge the capacitor, thus making it fairly obvious that the larger the resistance, the longer the charging process will take. In a similar fashion, it may be argued that the larger the capacitance, the longer the charging time will be, since the current needs to flow for a longer time to charge up the larger capacitor. It would be interesting to compare Faraday's initial explanation as published in 1854, Kelvin's explanations from analogues as published in his articles on cable theory (Thomson 1855a,b) and students' initial explanations. Faraday's and Kelvin's explanations relied on dynamic processes propagating along the length of the wire. A simplified explanation of the dynamic process as a function of time but not distance, as illustrated by the simple resistive-capacitive circuit, would likely be sufficiently challenging for students.

The repeated breaking of the cable as it was being laid makes it apparent that the dynamics involved are important. Simply hanging a cable into the water where it reaches the bottom at great depth, may itself be enough to break the cable, were it not designed properly. To see that aspect, students may use the original cable specifications of linear density and tensile strength (Thomson 1865). To calculate the tension, the buoyant force of sea-water will need to be taken into account. Students will then be able to follow the observation of Kelvin that the deepest water into which such a cable might be lowered is five nautical miles (Thomson 1865, p. 506). Kelvin's derivation of the dynamics of releasing the cable into the water from a moving ship requires student knowledge of mechanics and mathematics at least at the intermediate university level. Students uncover a number of interesting issues when solving the cable dynamics problem. Of particular note are Kelvin's observations that due to the drag forces on the cable its tension at the bottom of the ocean will be zero and under that condition the cable inside the water will form a perfectly straight line, which is the limiting case of a catenary. The tension which must be maintained in the upper end of the cable is critical, in that the cable must be released at a speed to match the motion of the ship through the water exactly. Although a problem like this one is challenging for students and requires considerable guidance from the instructor, it shows how mathematics and mechanics may be employed in 'real world' situations – a somewhat novel and refreshing experience for students.

7. Observations

The Atlantic cable story has served as motivation for an experimental and theoretical investigation by a senior physics laboratory class on two separate occasions. Students are provided with a long coaxial cable (about 300 m in length) to represent an 'Atlantic cable'. Working in groups, students design experiments to measure electrical characteristics, such as resistance, capacitance, inductance, and signal risetime, which also requires knowledge of the length of the cable. At this point, students will not have the experience or self-confidence to design such investigations entirely on their own, and the instructor will need to provide guidance. Figure 2 shows a spontaneously generated set of student planning notes, which outline the areas they planned to investigate. The reader will note that most of the questions identified as being raised in the context are present in the abbreviated student plan. The working out of the procedure was made more interesting owing to the length of the cable which had to be unwound many times around the perimeter of a large room in order to measure the characteristics with the cable uncoiled. Some students chose to work out the equations for the electrical characteristics of the cable and compare them to measurements. Others chose to work out the dynamics equations of Kelvin and make sense of them.

A number of indications were observed to suggest that the 'story-driven' approach yields a heightened degree of student motivation and engagement. These qualitative data may serve to guide further developments of such contexts. I observed that students employed a higher degree of creativity than they would with traditional laboratory activities; for instance, they devised an elaborate method of measuring the cable length with a standard length of string and duplicate counting and recording so as not to make a mistake. As another example of the type of engagement present, I note the reaction of one student to the Maxwell poem: 'This is the first poem I have ever heard that I liked!' Other indicators of motivation were students' willingness to speak with me (and other faculty who were not involved) about their activities and frequent episodes of laughter during



Electrical:

tables of measurements

- time constant $(\frac{1}{RC})$ (measured and calculated)
- speed of light
- pulse shape-change
- signal-delay

Mechanical

assumptions diagrams

- finish the equations
- estimates for real (cables, depth, ship)
- computer

Figure 2. Student Planning Notes.

the experimental investigations. Kubli notes that '[i]t has sometimes been noted that a lesson without any festive laughter in the class is sterile and fruitless' (2005, p. 527). The final exercise of the students was to prepare and present a polished public presentation of the results of their investigations to the general university community. Although it takes 'nerve' for most undergraduate students to make public presentations, students in my classes have invariably told me that preparing and presenting results of their investigations has been the most beneficial learning experience for them.

Teaching experiences like the one outlined here have been the most rewarding for me and also for my students. Nevertheless, they can be somewhat unsettling since they force both the teacher and the student to 'venture into uncharted waters'. Perhaps, this is one reason why methods like those outlined here have been slow to gain widespread adoption.

8. Future Development Plans

The Atlantic Cable Story and its instructional implementation is a small aspect of a large program of research upon which we have embarked in

Winnipeg. We are pleased to report that we have been able to obtain significant research funding to support our efforts for the next 5 years. We wish, first of all, to become proficient at designing and writing effective historical contexts and associated stories. These efforts are being guided by qualitative research observations as to the efficacy of the stories and contexts. Second, we are researching assessment instruments to measure students' attitudes and motivation, students' beliefs about the nature of science, and students' conceptual knowledge in the relevant areas of science curriculum. We wish to be able to assess all three areas in a single session so that historical contexts may be tested in greater depth as to their effect. The levels of application range from middle years science to university. Given a multi-function or multi-part assessment instrument, research questions can be formulated to measure the effectiveness of our approach for attitudes, beliefs, and knowledge of students, and also for teacher attitudes and effectiveness. Ultimately, we intend to disseminate teacher resources and suggested instructional materials, including booklets and an extensive website. We have found, in our workshops with science teachers, that they are *expecting* that academics will publish complete historical cases that have both significance and validity, so that they can begin to use them in the classroom.

Appendix: A Literary Story

The Galvanometer

The telegraphic cable-laying ships, the *Agamemnon*, and the *Niagara*, finally met in mid-Atlantic on July 29, 1858. Professor Thomson was stationed aboard the *Agamemnon*. It is rather an exciting occupation to watch the tell-tale signals on the Professor's galvanometer as the cable pays out. Indeed, it is almost impossible to realize the anxiety and *heart-interest* everybody manifests in the undertaking. Few, but the crew, even sleep soundly. Professor Thomson frequently does not put off his clothes at night.

Tonight, but a few hours after starting, there was an alarming crisis. The *Agamemnon* had signalled to the *Niagara*, 'Forty miles submerged,' and she was just beginning her acknowledgment, when suddenly, at 10 PM, communication ceased. According to orders, those on duty sent at once for Dr. Thomson. He came in a fearful state of excitement. One of the crew overheard him muttering to himself as he came: 'I shall have to use the bridge arrangement of Professor Wheatstone'. He supposed the fault might lie in a suspicious portion, which had been observed in the main coil, as, indeed, the tests confirmed. Not a second was to be lost, for it was evident that the damaged portion must be payed overboard in a few minutes; and, in the meantime, the tedious and difficult operation of making a splice had to be performed. Nearly all the officers of the ship and of those connected with the expedition stood in groups about the coil, watching with intense anxiety the cable as it slowly unwound itself nearer and nearer the joint, while the electricians worked at the splice as only persons could work who felt that the life and death of the expedition depended upon their rapidity. When the splice was finished, the signal was made to loose the brakes, and the repaired section of cable passed overboard in safety.

Attention now turned to the electrical room where the scene was such as those present shall never forget. The two clerks on duty, watching, with the common anxiety depicted on their faces, for a propitious signal; Dr. Thomson, in a perfect fever of nervous excitement, shaking like an aspen leaf, yet in mind clear and collected, testing and waiting, with half-despairing look for the result. Behind, in the darker part of the room, stood various officers of the ship. Round the door crowded the sailors of the watch, peeping over each other's shoulders at the mysteries, and shouting 'gangway!' when any one of importance wished to enter. The eyes of all were directed to the instruments, watching for the slightest quiver indicative of life. Such a scene was never witnessed save by the bedside of the dying. Things continued thus. After some minutes, Dr. Thomson and the others left the room, convinced they were doomed to disappointment. Suddenly one sang out, 'Haloa! the spot has gone up to 40°'. The clerk at the measuring instrument bolted right out of the room, scarcely knowing where he went for joy; ran to the deck, and cried out, 'Mr. Thomson! the cable's all right; we got a signal from the *Niagara*'. When the first stun of surprise and pleasure passed, each one began trying to express his feelings in some way more or less energetic. Dr. Thomson laughed right loud and heartily. Never was more anxiety compressed into such a space of time and never was there more relief. The entire incident of signal failure lasted exactly one hour and a half, but it did not seem a third of that time. Afterward, we learned that a faulty sand battery aboard the *Niagara* had prevented them from responding to our signals immediately. (Adapted from Thompson 1910, pp. 361–363 and Bright 1903, pp. 119–121)

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