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Ideas for enhancing primary and high school science education

Did you Know?

Restarting a Heart

Contrary to the idea commonly portrayed in television programs, a defibrillator (a device that uses paddles to deliver an electric current across the chest) is of no use in trying to restart a heart that has stopped beating. This condition is called asystole, and the lack of any electrical activity in the heart shows as a flatline on an ECG (electrocardiogram). Unfortunately, the treatments for asystole are not very effective.

A defibrillator works only if there is already electrical activity in the heart, as in the cases of ventricular fibrillation (VF) and ventricular tachycardia (VT), two conditions in which the heart also stops pumping blood. In VF, the electrical signals cause different parts of the heart muscle to beat in an uncoordinated way, while VT refers to the heart beating regularly but too quickly to pump blood.

Science Story

The stories in this regular section of *SER* may be used to enrich lessons and make them more interesting.

The Mirror Galvanometer

Before he became the first scientist to be knighted, Lord Kelvin went by the name William Thompson and was involved with laying of the trans-Atlantic electrical cable linking Europe and North America. A basic problem with transmitting signals through such a lengthy cable was that the current tended to be so low as to make signals difficult to detect using a standard galvanometer, which comprised a needle that was deflected by the magnetic field of the current.

Standing in his study one day and twirling his monocle--an eyeglass for correcting defective vision in one eye, and held in place by facial muscles--Thompson noticed sunlight that was entering through a window being reflected off the monocle and causing a spot of light to zoom around the room. The idea of the mirror galvanometer (where a mirror replaced the needle previously used) had been born. This device could not only detect signals 1000 times fainter than alternative receivers, but also allow Morse code to be read 10 times the previous rate.

Source: Erlichson, H. (2006). Kelvin and the trans-Atlantic cable. *The Physics Teacher*, *44*, 426-427.

The Use of History of Science Texts in Teaching Science: Two Cases of an Innovative, Constructivist Approach

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Abstract

This study proposes an empirical classification of ways to introduce elements of the history of science into science teaching, as well as describing a special way to do so characterized by the introduction of short extracts from historical texts. The aim is to motivate students to participate in problem-solving activities and to transform their alternative conceptions about various natural phenomena. Finally, the study presents two cases of introducing the history of science into the teaching of science in Greece; the basics of Electromagnetism (primary level) and the Simple Pendulum (lower grade of secondary education).

Introduction

The use of elements of the history of science in teaching is related to, among other things, the integration into teaching of the epistemological distinction between the framework within which scientific knowledge is born and developed and the framework within which scientific knowledge is an already organized body of issues, contents, and theories (Kuhn, 1962). If the answer to the question of introducing this distinction to teaching science is affirmative, then the equally interesting question arises of the role that each one of these contexts may play in teaching. Is it absolutely necessary to make this distinction in teaching science and, if so, what is the role of the history of science (i.e., of the field that is related to the context of the birth and development of new scientific knowledge)? Answers to the above questions may be provided legitimately by areas relevant to the subject, such as Epistemology, as well as by areas related to education (e.g., pedagogy or science education).

This work explores the above-mentioned questions using methodological tools from the field of science education. First, we will propose an empirical classification of the ways of introducing elements of the history of science into science teaching in order to deal with the issue of the distinction mentioned above. Second, we will explore the features of a particular approach that we believe contributes to the functional aspect of the issue, naming this method *introducing history of science texts into science teaching*. Finally, we will describe two cases of this method of introducing elements of the history of science into teaching science, one in primary and the other in secondary education.

Ways of Introducing Elements of the History of Science Into Teaching Science

Various proposals concerning the contribution of the history of science to science teaching began to be drafted in the early 20th century (Seroglou & Koumaras, 2001). However, integration of elements of the history of science into science teaching seems to acquire a different meaning depending on the kind of transformation scientific knowledge undergoes when it becomes a school subject (school knowledge). In past studies, we have argued that, with regard to a thematic curriculum like the Greek one, it is possible to distinguish among three basic transforming categories: the traditional, the innovative, and the constructivist approaches (Koliopoulos & Constantinou, 2005; Koliopoulos & Ravanis, 2000).

In the traditional approach, elements of the history of science are either absent or introduced in a fragmented way (with biographical details of scientists, or small texts describing the results of a scientific discovery, added to the main text), without any attempt to relate with the other two dimensions of scientific knowledge; the conceptual and the methodological. In essence, it is an approach that does not accept the introduction of the framework in which scientific knowledge is born and developed into the teaching of science.

In the innovative approach to the curriculum, characterized by the formation of wider thematic and conceptual units, the "deeper" discourse of a conceptual framework and the organic enclosure of the cultural dimension of science in the various thematic units, the introduction of elements of the history of science may take various forms. One of these is the introduction of elements of the history of science as a structural principle of the curriculum. The most representative example of this is the famous Project Physics Course which appeared in the USA in the early 70s (Holton, 2003). The large-scale introduction of elements of the history of science was linked not only to an attempt to create a positive stance towards science, but also towards improving the cultural dimension of scientific knowledge (e.g., aspects of scientific knowledge related to the social context of science, through a change in philosophy of the science curriculum). However, the emergence of the framework within which new scientific knowledge is born and developed appears as an autonomous goal, without any indication of a close relationship between the historical elements and the conceptual and methodological dimensions of scientific knowledge. As Holton mentions in his book: "I had in mind that in this course a college student might take in physical science, one really must present not only good science, but also something solid on the way science is done and grows, on the scientific worldview, on how the sciences are interrelated with one another and with world history itself" (pp. 779-780). These parallel ways, the discovery framework and the explanatory framework, are also observed in the Greek version of this approach that is elucidated in the school textbook *Physics for Multisectoral Lyceum* (Dapontes, Kasetas, & Skiathitis, 1984).

The appearance of the constructivist approach[1] to the teaching and learning of science brought back the debate on the ontogenesis and phylogenesis of scientific knowledge by upgrading the role of the history of science in the exploration of the conceptual representations of students regarding natural phenomena and the concepts of science (Halbwachs, 1974; Strauss, 1988). At the same time, efforts have been made to structurally link the introduction of elements of the history of science to the conceptual and methodological dimensions of scientific knowledge (Guedj, 2005; Irwin, 2000; Raftopoulos, Kalyfommatou, & Constantinou, 2005). The introduction of conceptual models from the history of science is a characteristic example of such an approach. In this case, teaching materials deriving from the analysis of elements of the history of science can contribute to the development of teaching interventions that aim to transform students' alternative conceptions when they approach natural phenomena and the concepts that explain them. For example, Monk and Osborne (1997) suggest a teaching model for the incorporation of the history of science into science teaching where the dominant element is the comparison of ideas deriving from the history of science, students' ideas, and contemporary ideas in a thematic scientific field. The final goal is the solution of the conceptual conflicts caused by the controversies in students' thinking. Also, Seroglou, Koumaras, and Tselfes (1998) developed a research instrument with which it is possible to design teaching activities inspired by the history of science and which aims at students' cognitive progress. This instrument was applied in the cases of mechanical phenomena (with experimental activities inspired by the work of Galileo) and electromagnetic phenomena (with experimental activities inspired by the work of Gilbert and Faraday), demonstrating that students of compulsory education participating in these activities presented cognitive progress. Also, Dedes (2005a, 2005b) used material from the history of optics, and mainly the decisive experiment through which Kepler explained the optical paradox of the change in shape of the luminous print on the ground when sunlight passes through the leaves of a tree, to design teaching materials aimed at the transformation of students' conceptual representations of the rectilinear transmission of light.

The Introduction of Short Extracts From Historical Texts

One of the techniques used in the framework of this approach uses authentic or transformed historical material (mainly text) which is often linked to the so-called story-line approach. It concerns a "local" approach of the curriculum, according to which the teacher may use functional texts from the history of science as opportunities for reading and contemplation as well as for comparison or correlation. The aim here is for "the students to compare their progress in relation to the epistemological obstacles overtaken by scientists in the past" (Martinand, 1993, p. 96). In this case, an effort is made to combine the discovery framework and the explanatory framework. Stinner, MacMillan, Metz, Jilek, & Klassen (2003) suggest to teachers of all grades a methodological instrument for creating historical material that may take the form of short extracts from historical texts (vignettes) or case studies where the unifying central idea leads to the creation of stories with the use of authentic historical material. The important point in the story-line approach is that the historical material is followed by teaching situations based on the introduction and solving of problems that should interest students (Roach, 1993). One of the advantages of the creation and introduction of texts from the history of science, within the framework of the story-line approach and their localized use, is the acceptance by teachers who may use short and functional material (Monk & Osborne, 1997) and, in addition, are not obliged to form complete perceptions of the history and philosophy of science.

In the following paragraphs, we will describe the content of two cases of the use of texts from the history of science in the Greek curriculum. The first case refers to primary education and concerns the teaching of electromagnetic phenomena, while the second refers to secondary education and concerns the teaching of the simple pendulum.

The Use of Texts From the History of Science: Two Cases

Case One: The teaching of electromagnetism in the sixth grade (primary education). The entire teaching process consists of three units and has been designed to serve an innovative, as well as a constructivist, approach to the science curriculum. Before being introduced to the concepts of electromagnetism, Grade 6 students in Greece have already been taught about simple electrical circuits in the fifth and sixth grades. In the first unit, text from the history of science is introduced with the goal of creating an instructional framework for the introduction and the study of the relationship between magnetism and electricity (see Appendix A). This text functions as a problem situation in which students express their beliefs concerning this relationship. Then, the relationship between magnetism and electricity is introduced again in the form of a short text (vignette) involving Ørsted. In parallel, the students are encouraged to formulate a viewpoint of the confirmation of the phenomenological relationship between magnetism and electricity, which led to shape a version of Ørsted's experiment. The students are called upon to assess, on a metacognitive level, the ideas and views of scientists who initially addressed the existence, or non-existence, of the relationship between electricity and magnetism. The aim is for students to transform their own perceptions, which were expressed at the beginning of the teaching process.

The other two units focus on the study of the electromagnet and the electric generator, adopting a similar form of using short texts from the history of electromagnetism.

This case displays more the characteristics of an innovative approach, and especially the characteristic of the organic link between the cultural component of scientific knowledge and the other two components. The students are motivated to participate in problem-solving activities in which the social context, shaped by historical text, guides the building of knowledge. The exact opposite occurs in the traditional approach, in which the cultural component appears simply as applications of science concepts in issues of everyday life and technology. Moreover, even though this text contains no explanatory information, we claim that the proposed teaching may potentially activate mechanisms that are involved in a constructive approach to teaching, such as the mechanism of cognitive conflict. In the case of electromagnetism, this mechanism may be activated through the destabilization of the idea, on the part of the children, that there is no relationship between magnetic and electrical phenomena. A first analysis of the dialogue among students shows that the use of historical material in the form of short texts does not only contribute to the active participation of students, but also seems to help students in the process of formulating predictions and hypotheses (Stamoulis, 2005).

Case Two: The study of a simple pendulum in the ninth grade (secondary education). This case comprises a total of four units for teaching about the simple pendulum and its relation to accurate timekeeping, and serves the innovative, as well as the constructivist, approach to the science curriculum. In the traditional teaching of the pendulum, various conceptual frames are usually involved, such as Newtonian mechanics or energy conservation (Koliopoulos & Constantinou, 2005). However, in the approach suggested here, there is a deep exploration of the frame of the pendulum's isochronous movement as observed by Galileo. At the same time, there is the knowledge that, at this particular grade level, the basic conceptual problem for the students is the understanding of isochronous movement as well as the concept of the time period (Dossis & Koliopoulos, 2005). The link between the simple pendulum and the mechanisms of timekeeping enhances, on the one hand, the cultural aspect of scientific knowledge while, on the other, giving meaning to the study of the conceptual and methodological aspects of knowledge.

The foregoing rationale is served by the introduction of two short texts into teaching that include elements from the history of science. (Please see Appendices B and C for a complete schedule of activities for this case, and corresponding worksheets, respectively.) The first text refers to an extract from Galileo's book *Dialogues Concerning Two New Sciences*, and concerns the isochronous movement of the pendulum. This text is introduced in relation to problem-solving practice and aims mainly at making students discuss the paradox of the pendulum's isochronous motion; for example, a) "How do you think Salviati (the person expressing Galileo's views) would respond to the views of Sagredo?" b) "What technique would you suggest to examine whether Sagredo's claim is true or false?" In the second text, the discovery of the astronomer J. Richer is described. According to him, the length of the pendulum for counting seconds, which was set up in Paris, should have been reduced in order for the pendulum to continue to count seconds in Cayenne (Matthews, 2000). This text is related to the formulation by students of hypotheses about the factors that influence a pendulum's periods. The analysis of the discussion among students is under development (Dossis, 2005).

Conclusion

Introducing the elements of history of science, via short texts (vignettes), into the framework of the story-line approach seems to be an approach that offers multiple benefits. It is linked to ideas in the curriculum that transcend the traditional point of view in which the cultural dimension of scientific knowledge is undervalued. It seems to contribute to students' understanding of concepts and methods and to the creation of positive attitudes towards science, while also familiarizing the teacher of compulsory education with elements of the history of science. More research towards assessing this approach in relation to the cognitive and emotional progress of students and its broadening, such as its transposition to the field of teacher training, are necessary preconditions for the creation of a valid notion of the precise role that the introduction of elements of the history of science can play in teaching science.

Notes

[1]In this text, the term *constructivist* approach is used in the context of a French research tradition according to which the planning of curricula results from (a) the epistemological analysis of the content of the thematic unity to be taught, (b) the cognitive pre-instructional traits of the students that the curriculum is targeting, and (c) the features of the educational system within which the curriculum is being implemented (see, e.g., Artigues, 1988; Koliopoulos & Ravanis, 2000; Tiberghien, Psillos, & Koumaras, 1994).

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Appendix A

Worksheet for Unit 1 of Case 1: Electromagnetism

1. The following text describes a strange incident concerning the effect of a lightning storm on a boat's compasses.

> He tells me, that being once master of a ship in a voyage to Barbados, in company of another, commanded by one Crofton of New England they were, in the latitude of Bermuda, suddenly alarmed with a terrible clap of thunder, which broke this Crofton's fore-mast.
>
> By the time the noise, together with the danger of this frightful accident, was past, Mr. Howard, to whom this thunder had been more favorable, was however no less surprised, to see his companion's ship steer directly homeward again. At first he thought that perhaps the confusion, that the late mischance had put them in, might have made them mistake their course, and that they soon perceive their error. But seeing them persist in it, and being by this time almost out of call, he tacked and stood after them; and as soon as he got near enough to be well understood, asked where they were going.
>
> But their answer and by the sequel of their discourse, it at last appeared that Mr. Crofton did indeed steer by the right point of his compass, but that the needle was turned round, the North and South points having changed positions. Upon examination he found every compass on the ship in the same state. This strange and sudden accident he could impute to nothing else but the operation of the lightning or thunder newly mentioned. He adds, that he lent Crofton one of his compasses to finish the voyage; and that those thunder struck ones did never to his knowledge recover their right position again.
>
> (Source: *Philosophical Transactions*, Vol. 27, Dublin, May 10th, 1676)

What is your own explanation of what happened to the boat's compasses?

2. In 1820, while lecturing on electricity, Hans Christian Øersted connected the poles of a battery with a wire. Surprisingly, he observed that the compass dial, found on the table close to the wire, started to move from its initial position. This observation preoccupied Øersted and, later, when he was alone, he repeated the experiment many times. Later on, he wrote:

> While I prepared the presentation of an experiment, I turned to the movement of the magnetic compass needle during lighting and at the same time I supposed that an electric circuit was affecting this movement. I tried to prove it by making the following experiment. I brought the magnetic compass needle close to an electric circuit. The movement was profound, but it seemed strange and so I postponed the experiment to a later time. In July I repeated the experiments and I reached the conclusion we already know.

Try to repeat Øersted's experiment with the material available to you.

3. (a) How do you explain the movement of the magnetic compass needle?
   (b) Compare the behaviour of the magnetic compass needle when you move it close to a magnet, and then to a wire belonging to an electric circuit.
   (c) Is there any relation between electricity and magnetism?

Appendix B

Schedule of Activities for Case 2: Simple Pendulum

Schedule of activities (Teaching Unit 1)			
Actions of teacher / problem situations	Expected actions of students	Student products	Educational documents
1. Name the pieces of apparatus you have seen in the film and discuss their possible uses and usefulness.	• Name the different kinds of clocks and conclude that these are timekeeping apparatuses.		• Film concerning three kinds of clocks; the sundial, hourglass, and pendulum clock.
2. What are the similarities and differences between the three types of clocks in how they measure the duration of an event?	• Refer to the periodicity and accuracy of each type of clock..	Worksheet 1	
3. Which is the most important advantage of timekeeping with a pendulum clock over the two other types of clocks?	• Conclude that timekeeping with a pendulum clock is more accurate than timekeeping with the other types.		
4. Closing discussion.	• Recognize the necessity of accurate timekeeping.		

Schedule of activities (Teaching Unit 2)			
Actions of teacher / problem situations	Expected actions of students	Student products	Educational documents
1. Discussion of the text. How do you think Salviati (i.e., the character who expresses Galileo's ideas) would go about giving a convincing answer to Sagredo's claims?	• Put forward ideas on how to confirm the isochronous movement of the pendulum.	Worksheet 2	• Historical text: Galileo and Timekeeping.
2. What specific technique would you use in order to verify Sagredo's claim?	• Propose a suitable technique to determine, through experimentation, the independence of the period of the pendulum and the amplitude of oscillation.	Worksheet 3	
3. Adoption and implementation of a technique (demonstration experiment or group work).	• Measure the period of the pendulum.		• Laboratory apparatus concerning a simple pendulum.
4. Closing discussion.	• Conclude the independence of the period of the pendulum and the amplitude of oscillation.		

Schedule of activities (Teaching Unit 3)

Actions of teacher / Problem situations	Expected actions of students	Student products	Educational documents
1. Discussion of how a simple pendulum is transformed into a pendulum clock of period 2 seconds (i.e., a single swing time of 1 second).	• Suggest the length of the string as a factor that influences the period of the pendulum.	Worksheet 4	
2. Can you propose a suitable technique to confirm, through experimentation, your assumption that the length of the string influences the period of the pendulum?	• Propose a suitable technique to control, through experimentation, the dependence of the period of the pendulum on the length of the string.	Worksheet 5	
3. Adoption and implementation of a technique (demonstration experiment or group work).	• Measure the period of the pendulum.		• Laboratory apparatus concerning the simple pendulum.
4. Closing discussion.	• Conclude that the pendulum clock with period 2 seconds (swing time 1 second) has a string length of approximately 1 meter.		

Schedule of activities (Teaching Unit 4)			
Actions of teacher / problem situations	**Expected actions of students**	**Student products**	**Educational documents**
1. Discussion on the text. Which in your opinion is the factor that influenced the results of the measurements kept by Richer in Cayenne?	• Recognize that the pendulum clock in Cayenne is slow (i.e., its single swings take longer than 1 second). • Assume the dependence of the period of the pendulum on gravity.	Worksheet 6	• Historical text: The Voyage of Jean Richer to Cayenne. • Tracing of the trip on a desktop globe.
2. In which ways could someone confirm, or discredit, the idea that period depends on gravity? (Specifically, the greater the gravity, the smaller the period becomes.)	• Propose a suitable technique to confirm, through experimentation, the dependence of the period of the pendulum on gravity.	Worksheet 7	
3. How could this problem be resolved in those times?	• Propose the change of the length of the pendulum, or the use of a clock with timekeeping that does not depend on gravity.		
4. Which solutions would you suggest today? Closing discussion.		Homework (optional)	

Appendix C

Worksheets for Case 2: Simple Pendulum

Worksheet 1

1. What are the similarities and differences between the three types of clocks in how they measure the duration of an event?
2. Which is the most important advantage of timekeeping with a pendulum clock over the two other types of clocks?

Worksheet 2

Historical Text 1
Galileo and Timekeeping

The year 1638 was an historic one for science. Galileo published his work Dialogues Concerning Two New Sciences, one of the first written records of the birth of modern Physics. Galileo wrote this in the form of a play and discussed his ideas through its three main characters: Salviati, a brilliant scientist, who expresses Galileo's beliefs, Sagredo, a clever amateur disguised as a neutral participant, and Simplicio, the well-meaning defender of the ideas of the time. The following excerpt deals with pendulum motion (i.e., it is related to today's lesson).

> *Sagredo*: "I have observed, thousands of times, the swinging of chandeliers, especially in churches, or lamps hanging from the ceiling and moving to and fro. But the only thing I have established from these observations is that it is most unlikely that the opinion of those people who claim that all these oscillations are maintained by the environment is correct. For, if that were the case, then the wind would have to act with great insight and have nothing else to do than to give this suspended weight a perfectly regular to-and-fro motion. It is impossible for me to imagine that the same body, suspended from a string of approximately 50 meters, and moved away by 90 degrees (90^o) from its perpendicular position and then one degree (1^o) from the perpendicular position could, in both cases, take the same time to cover a very large arc and then next a very small one. That seems to me very unlikely."

How do you think Salviati, the character who expresses Galileo's ideas, would go about giving a convincing answer to Sagredo's claims?

Worksheet 3

What specific technique would you use to verify Sagredo's claim?

Worksheet 4

How could you transform a simple pendulum into a pendulum clock that takes 1 second to complete a single swing (i.e., that has a period of 2 seconds)?

Worksheet 5

Can you propose a suitable technique to control through experimentation your assumption that the length of the string influences the period of the pendulum?

Worksheet 6

Historical Text 2
An Exciting Discovery: The Voyage of Jean Richer to Cayenne

> In 1672, the astronomer Jean Richer was sent on a scientific mission by the French Academy of Sciences to the city of Cayenne, which is in French Guyana near the equator. Richer had a pendulum clock with him, which had been set in Paris to oscillate in periods of 1 second. On observing the pendulum in Cayenne, Richer made an unexpected discovery; the pendulum clock was slow by 2.5 min each day.
>
> Richer's claim that the 1-second pendulum clock slows down near the equator triggered a very interesting discussion concerning why this occurs. Some scientists doubted his measurements. In particular, Richer found himself in conflict with Huygens, the man who had constructed the clock Richer had with him.
>
> Others tried to interpret the results of these measurements. They claimed that the assumption that the period of the pendulum depends only on the length of the string is not valid. In this way, they tried to identify other factors that could influence the period, and this was in fact shown to be correct!

Which in your opinion is the factor that influenced the results obtained by Richer in Cayenne?

Worksheet 7

1. In which ways could someone confirm, or discredit, the idea that period depends on gravity (and specifically that the greater the gravity, the smaller the period becomes)?
2. How could this problem be resolved in those times?

Demonstration

Liquid Nitrogen Explosion

Needed. Liquid nitrogen, plastic soft drink bottle with cap, balloon, soft string, plastic bucket, and hot water.

Invitation. Invite students to predict what will happen when a little liquid nitrogen is placed in the plastic soft drink bottle and the opening of the balloon is stretched over the opening of the bottle.

Exploration. Try it, tying the string around the neck of the balloon to help prevent nitrogen leaking from the bottle/balloon system, and watch the balloon expand. Provided sufficient liquid nitrogen is used, the balloon will eventually explode.

Concept introduction. As the liquid nitrogen evaporates, it fills the balloon with more and more gas particles, thus increasing the pressure inside the balloon and causing the balloon to expand.

Extension. While the balloon eventually explodes, it does take quite some time to do so. Ask students to suggest a way to speed up the evaporation of the liquid nitrogen. When the idea of heating the liquid nitrogen is arrived at, try this by repeating the demonstration but this time placing the bottle, with balloon attached, in the plastic bucket containing some hot water and watch the increased rate of inflation of the balloon.

Then, tell students that you have just had another thought, and ask them to predict what might happen if this experiment was to be repeated but, instead of stretching a balloon over the opening of the bottle, the top was screwed onto the bottle. Try it, after first moving to an outside location and having students observe from some distance as you seal the bottle, drop it into the bucket containing hot water, and run! The resulting explosion is quite impressive, even destroying the plastic bucket. (To avoid the cost of a plastic bucket, replace it with some other waste plastic container, such as a vinegar bottle with the top cut off, and use a soft drink bottle that is small enough to fit inside.)

Science Poetry

Reading and/or listening to poems composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

Ode to Bacteria

O Bacteria
How microscopic you are
You are everywhere, near and far

O Bacteria
You cause diseases, yet are not viral
You can be red-shaped, spherical or spiral

O Bacteria
You move around with the help of your flagella
You are the mastermind behind E. coli, typhoid and salmonella

O Bacteria
It is you we blame for bronchitis
Pneumonia, cholera and bacterial meningitis

O Bacteria
Even you shall meet your end
By these pesky drugs, antibiotics, your worst friend

Pinky Latt, 14 years
Australia

Immunisations

One of the worst things in the world is to get an injection,
But they sure help you not to get an infection.

They are also known as vaccinations,
And people have them in most nations.

You have to go to the right location,
And all it does is give you a whole heap of frustration.

As nervous as can be and end up feeling a little jab,
Which personally doesn't make you feel that fab.

Into your body we inject a dead virus,
Our antibodies will eventually fight for us.

Measles and mumps, malaria and meningitis,
Tetanus and pertussis, tuberculosis and hepatitis.

Antibodies remain in the body for further attack,
In case any of them shall ever come back.

From very early on when you are a baby,
There should be no buts and certainly no maybes.

So don't be afraid of an inoculation
Then you can go on a wonderful vacation.

Marley Raeside, 14 years
Australia

Students' Alternative Conceptions

Students' alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children's science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

Reflection of Light

(a) Which of the following can reflect light: Paper, a dark rock, a grey rock, a gold coin, a rusted coin, milk, water, aluminium foil, an orange, rough cardboard, the Moon, clouds, a wooden table, a mirror, clear glass, coloured glass, candle wax, grass?

(b) *Optional*: List some of your own examples of things that you think reflect light and things that you think do not.
(c) Explain how you decided that something reflects light.

Comment. The best response to (a) is that all these objects reflect light. Light can be reflected, refracted, and/or absorbed by an object. While the term *reflection* is most often used in the context of mirrors, water, and smooth, shiny objects, all nonluminous objects (i.e., those that don't emit light themselves) that we can see reflect some light, because we see them as a result of the reflected light being received by our eyes. Reflected light allows clear glass to act as a mirror.

Objects appear coloured because they absorb some light colours but reflect the rest. White objects reflect all colours, while an ideal black surface will absorb all light (i.e., black represents the absence of light entering our eyes). In practice, though, the features of a black object can be seen because not all the incident light is absorbed. A rough, bumpy surface can look dull because the reflected light is scattered.

Teaching Techniques

This regular section of *SER* describes thinking, cooperative learning, and other teaching techniques.

Alternating Think-Pair-Share Review

For 1 minute, students think individually about the key ideas of a lecture, discussion, or whatever (e.g., ideas on a controversial issue) and summarize their ideas in point form. Then, during the next 2 minutes, pairs of students alternate the sharing of these ideas, one point at a time, adding missed points to their own lists. As an alternative, this 2-minute period can be divided into two 1-minute periods. During each of these periods, 1 student only shares his or her ideas while the other listens (and/or provides supporting comments but without offering his or her own ideas). The final lists, or a selection of them, can be shared (e.g., by displaying them or having students read them) with the whole class.

Source: Lin, E. (2006). Cooperative learning in the science classroom. *The Science Teacher*, *73*(5), 34-39.

Bell Work Tasks

Bell work tasks may be used during the first 3 minutes of class to focus students' thoughts on a topic, have them synthesize or revise ideas, connect previous learning to new ideas, and generate personal relevance of an idea, and can even expose misconceptions. While defining terms and solving numerical problems (e.g., calculate the frequency of a 750-nm photon) would be acceptable bell work tasks, it is better to use questions that facilitate higher-level thinking and have multiple correct answers, even providing the opportunity for students to share and defend responses. For example, a much richer task would be to ask students to calculate the wavelength of their favourite radio station and the time it takes a signal to travel from the radio station to their home. As another example, students might be asked to determine which sports would work better on a particular planet (e.g., Mars) than on Earth, and which ones would not.

To motivate students to participate in bell work, explain the value of such tasks to their learning and even consider asking them to submit their bell work for grading. Bell tasks also keep students occupied while a teacher tends to other tasks, such as marking the role or arranging materials, and it is useful to use a cooking timer to ensure the allowed time (e.g., 3 minutes) is not exceeded.

Source: Slater, T. F. (2006). The first three minutes . . . of class. *The Physics Teacher*, *44*, 477-478.

Travelling the Road Beyond the Curriculum Through a Science Fair

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Abstract

In this paper we describe a model for a science fair, within the context of an elementary science methods course. We first describe the theoretical perspectives from which the idea of science fairs derives and we provide definitions as we sketch the characteristics of commonly used science fairs. We then describe the context and processes of a science fair that was organized by a team of university instructors, prospective elementary teachers, school teachers, parents, and friends. We argue that the main contribution of this paper is that it provides a concrete example of a personally meaningful and science-relevant learning experience that combines formal and informal learning activities. The implications of this work are associated with paving the path towards exploring the question, "How can we travel the road beyond the curriculum?" as it provides the basis for intellectual conversations for the place of science fairs in formal education.

Prospective elementary teachers quite often complain that their learning-to-teach experiences in the university are far removed from the reality of the elementary school classroom. In an attempt to address this problem, we engaged prospective elementary teachers in the design and implementation of a science fair, within the context of an elementary science methods course. In our approach, the science fair focused on engaging elementary school students, under the guidance and supervision of prospective elementary teachers, in inquiry-based investigations: posing scientific questions, making observations, designing investigations, collecting data, analyzing data to form explanations, and communicating those explanations to others (National Research Council [NRC], 1996). The design of this science fair was conceptualized through perspectives on informal learning and particularly real-world learning situations.

Real-World Learning Experiences

Many researchers have argued about the impact of learning experiences that occur in out-of-school contexts such as museums, science centers, national parks, zoos, and other informal settings. While much research has been conducted in the area of informal learning within the past decade, it has occurred mostly within museum-like settings (Anderson, Lucas, & Ginns, 2003; Dierking, Falk, Rennie, Anderson & Ellenbogen, 2003). Nonetheless, there is clear evidence to support the notion that there is much learning happening in other "real-world" settings (Wellinghton, 1990). As Dierking et al. (2003) stated, "clearly lacking, though, are comparable studies of learning from film, radio, community-based organizations such as scouts, summer camps, home, friends, the workplace, the Internet, and a whole range of other real-world situations" (p. 109). Adding to this view we argue that also lacking are studies of informal learning within the context of "formal settings" such as teacher-preparation programs. This view actually guided us in designing this instructional intervention; a science fair within the context of an elementary methods course and essentially a community-based approach to science that involves prospective elementary teachers, elementary school students, teachers, university professors, parents, and friends. This real-world instructional intervention suggests the benefits of authenticity for science learning, given that it provides opportunities to experience not only the procedures and tools of science, but also the attitudes and social interactions that characterize science practice (Edelson, 1998).

The Science Fair

Science fair activities are focused on public exhibitions of students' science investigations and their main goal is to encourage student interest in science (Walker, 1992). The science fair can be utilized in the science classroom as an integrative system of formal and informal instructional activities. A review of the literature indicates that science fair has been used throughout the years in a variety of school settings mostly because of its potential to motivate students and facilitate positive student attitudes towards science. Through their engagement in a science fair, young learners are asked to carry out a scientific investigation and present their findings to other young learners or adults who visit the fair. In many cases, there also exist competitions in science fairs for the purpose of enhancing student motivation for participation. In our approach, we place emphasis on the learning of prospective elementary teachers instead of elementary school students, and herein is the innovation of this instructional intervention: a science fair in support of learning to teach science at the elementary school. In designing this science fair, we were exploring ways to provide prospective elementary teachers with learning experiences that were as close as possible to the realities of the elementary school classroom.

Beyond Covering the Curriculum

The design of the elementary science methods course was based on recent recommendations for reform illustrated by the *National Science Education Standards* (NRC, 1996) placing an emphasis on scientific inquiry. The purpose of the course was to support prospective elementary teachers in developing contemporary understandings of science teaching and applying those as they were being developed in practice through the design and implementation of the science fair. The main objective of the course was to support prospective elementary teachers develop a personal philosophy of science teaching and learning based on contemporary theoretical perspectives about teaching science as inquiry while placing emphasis on the role of evidence and explanation in science.

The first half of the course (6 weeks) was what we called the formal science phase of the science fair, as it was associated with formal instruction in the university classroom. During this phase, prospective elementary teachers were guided to develop conceptual understandings about scientific inquiry through seminal readings. Concurrently, outside of the classroom time, the instructor and the teaching assistant of the course made arrangements with a sixth-grade teacher at an urban elementary school to host the science fair in the school's yard. In an attempt to develop a common plan of action and mutual understanding and trust between herself, as a representative of the school community, and the prospective elementary teachers, the teacher visited the science methods course twice during the first half of the course. During her visits, she engaged in classroom activities with emphasis on scientific inquiry while rules of engagement in the science fair were established.

During the second half of the course (6 weeks), each prospective elementary teacher was assigned to either one or a pair of elementary school students and together they had to design and carry out a long-term, inquiry-based investigation. We refer to these activities as non-formal science as these were organized outside the formal system but were incorporated into the formal curriculum (Koliopoulos, 2003).

Procedures of the Science Fair

There were 60 prospective elementary teachers enrolled in the elementary science methods course, and 50 elementary school students from two sixth-grade classrooms, involved in this fair. The students were first asked to form questions that they would like to investigate. These questions were then refined and rephrased by the students in collaboration with the prospective elementary teachers and the teaching assistant in order to form testable questions. The work was basically done at different places in the schoolyard, or at the science lab, during school time and where appropriate arrangements for desks, chairs, and laboratory materials were made. During these times, school teachers, parent helpers, and the instructor and the teaching assistant of the course rotated around the working groups and provided support in the carrying out of the investigations.

Concurrently, the methods course continued to meet at the university while prospective elementary teachers had regular meetings with their instructor and teaching assistant during office hours to discuss design issues of their investigations and report on their progress. Moreover, the instructor and the teaching assistant of the course were in frequent communication with the teachers of the school in order to maintain a record of growth for each team of prospective teacher and student(s). At the same time, parents and other community volunteers were involved in organizing and managing the logistic aspects of the science fair, such as preparing printed invitations for the Ministry of Education, the University, schools, local community, and other organized groups.

The sixth-graders engaged in the investigations through specially-designed curriculum materials that placed emphasis on designing experiments and aimed to support the development of inquiry skills (Constantinou & Learning in Sciences Group, 2004). In general, the investigations involved interaction with, and manipulation of, simple materials, collection, analysis, and interpretation of data, and representation of findings in a variety of formats. The final outcomes of the investigations were, in most cases, a poster which described both the process and findings of the investigations, a related interactive activity, and a game or demonstration associated with the investigation. Examples of investigations carried out at the fair are: (1) What causes a boat to travel faster? (2) What factors are associated with how far a paper plane can fly? (3) What factors are related to the length of a string? (4) What factors affect the length and direction of shadows? (5) What factors affect the pressure of gases? (6) What causes a balloon to float? (7) What factors are related to the growing of plants? (8) What causes a pendulum to swing? (9) How can we help sand concentrate more heat from the sun? (10) Why are different kinds of sounds produced by hitting on different types of bottles?

At the end of the 6-week engagement in investigations, the school organized an all-day public event where each working group of prospective elementary teacher and elementary school students communicated both the processes and the findings of their investigations using interactive posters, exhibits, and demonstrations. We characterize these activities as informal science activities since they were activated outside the formal educational system (Koliopoulos, 2003). The exhibits and demonstrations engaged the public in a specific aspect of their investigation through an interactive activity, scientific experiment, and/or a game. The involvement of the public (i.e., parents and friends) in the interactive exhibits is of immense importance as one of the baseline design strategies of the science fair is to nurture a symbiotic relationship between the university, the school, and the local community.

Evidence of Success

Participation in the science fair was beyond our expectations. The presence of a great number of family and friends of the students, as well as the prospective teachers, provided a sense of community and relevance to science on that day. Teachers, grandparents, young brothers and sisters of the students, and the prospective teachers all participated in scientific experiments and interactive games with great enthusiasm. Beyond the great enthusiasm from all communities that was conspicuous on the day of the science fair, anecdotal evidence from prospective teachers' reflective journals provides support to the notion of success of this science fair. For example, in her reflection statement, a prospective teacher indicated that the science fair, for her as a future teacher, was beneficial because it modeled an innovative way of teaching science, which differed considerably from what is usually observed in an elementary school classroom. This response was typical of the rest of the prospective teachers' statements, which pointed out that the science fair was an exciting and growing experience that brought together the school, the university, and the community and helped them understand how a variety of activities, both in and out of class settings, can support student learning. Other prospective teachers found it exciting that the students decided upon the topics to be investigated, which in turn enhanced their motivation to participate. The main drawback of the science fair, as identified by some prospective teachers, is that it requires a lot of effort and time, which is usually a problem for teachers. Most of the prospective teachers stated that the science fair was successful because a great number of people were involved and they were unsure if they would be able to organize science fairs in the future without the support of their colleagues.

Perhaps most notably, and with rare exceptions, prospective teachers elaborated on the issue of identifying connections between science and society through the design and implementation of the science fair. Also of significance is the fact that all prospective teachers stated that they found very beneficial the opportunities to work closely with elementary school students in the school environment. From our perspective, as teacher educators, the science fair was a success since it achieved its main goal; it provided prospective elementary teachers with an empowering learning-to-teach science experience adjacent to the realities of the school classroom. It became evident to us, both through our own engagement in the science fair and our observations of prospective teachers' participation and analysis of their reflective journals, that the science fair was a growing experience for them as future teachers. The majority dedicated a lot of their personal time to the design and implementation of the science fair as they invested much energy in constructing the knowledge and developing the skills needed to engage students in a variety of inquiry-based tasks.

Concluding Thoughts

Our experiences suggest that designing and implementing a science fair has the potential to be a worthwhile and empowering learning-to-teach experience for prospective elementary teachers as they attempt to find personal relevance in science and construct theories of teaching through their preparation to teach. As we think of better ways of implementing science fairs in the future, we focus our attention on exploring in further detail the potential of going beyond the curriculum and providing prospective teachers with empowering, real-world science learning experiences. Future steps in our work will focus on researching the ways in which engagement in a science fair would be fruitful in proposing a new conceptualization of the nature of science on the premise that science is socially structured as much as science influences the structure of the society (Kuhn, 1962).

Acknowledgements

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Ideas in Brief

Summaries of ideas from key articles in reviewed publications

Open Days Portray a False Image

Secondary schools in the UK commonly host open days for students from feeder primary schools. While other subjects might exhibit textbooks and examples of students' work, science departments typically focus on portraying science as a fun, exciting, enjoyable, hands-on activity that need not be conceptually demanding and in which "whiz, bang, pop" experiences are usual.

While this may create short-term interest in science, Abrahams (2007) sees it as problematic. By not truthfully portraying "normal" school science, this approach creates unrealistic expectations about the nature of science and an unsustainable image of science, which in turn leads to disappointment in students with the reality of subsequent school science.

Science is the study of the natural world, in which there are limited exciting flashes, pops, and bangs. Also, it is not an essentially hands-on pursuit, and does require engagement of the mind. It would be preferable to show students that the excitement associated with science comes from the intellectually fascinating task of trying to understand nature rather than in merely producing spectacular phenomena.

Reference

Abrahams, I. Z. (2007). An unrealistic image of science. *School Science Review*, *88*(324), 119-122.

The Myth of Teaching to Learning Styles

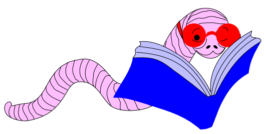
Because people have different preferred learning styles, it may appear attractive to teach a class in multiple ways or, better, to preassess students as to learning style and personalize lessons in this regard. However, there is no valid evidence to support the notion that tailoring instruction to different learning styles is productive (Olson, 2006). Indeed, such an approach can actually be detrimental, as students learning using their preferred learning style can invest a reduced effort and, as a result, learn less.

Rather, Olson (2006) recommends that we make use of what we know about the similarities in how people learn and:

- use concrete representations before introducing abstractions (as is promoted by the learning cycle and other inquiry-based instructional models),
- teach a concept using representations that best suit the content itself (e.g., teach sound by using sound), and
- provide opportunities for students to test their prior knowledge (including their misconceptions), to be introduced to scientific ideas, and to modify their thinking so as to be in accord with best scientific understanding.

Reference

Olson, J. K. (2006). The myth of catering to learning styles. *Science and Children*, *44*(2), 56-57.



Research in Brief

Summaries of research findings from key articles in reviewed publications

Teachers' Emphasis on Evolution in Biology

The science education standards of the state of Minnesota, United States of America, include evolution, and the teaching of creationism (e.g., intelligent design) in public school science classrooms in this state is unlawful. While, in conversations with biology teachers, Moore (2007) had found most claiming to emphasize evolution in their courses, he was curious that over several years students in his introductory college biology classes had scored much lower, on a first-day-of-class test, on evolution-related questions than on questions about other biological topics.

To investigate this situation, during 2002-2004 685 college students were invited to complete a voluntary, first-day-of-class survey about their perceptions of the teaching of evolution during their high school biology classes (95% response rate). Similar survey data were collected from 107 Minnesota high school teachers who, during one of two science education meetings (a national science teachers convention and a biology-life sciences teachers conference) in 2003, chose to complete a survey (R. Moore, personal communication, September 15, 2007).

Moore (2007) found that teachers claimed to be placing a greater emphasis on evolution than their students perceived, further concluding that creationism is "alive and well" among biology teachers in Minnesota. Indeed, given the teacher sampling procedure adopted, the data obtained may well under-represent the true extent of creationism among biology teachers in Minnesota, as those attending professional meetings may be more likely to accept evolution and teach according to the state science education standards than other teachers. Students also expressed a desire to spend more time on these topics, and Moore recommends that this could be achieved by including more evolution in science classes and encouraging students to learn more about creationism by taking a comparative religion class.

Reference

Moore, R. (2007). The differing perceptions of teachers & students regarding teachers' emphasis on evolution in high school biology classrooms. *The American Biology Teacher*, *69*, 268-271.

(*Editor*: The author has subsequently reported: "Yes, I think the data does indeed under-represent the extent of creationism in public schools' biology courses. Two days ago we surveyed almost 600 freshman [overwhelmingly from Minnesota public schools] and 20% said that their high school biology class included creationism" [R. Moore, personal communication, September 15, 2007].)

Multiple Intelligences and Science Learning

By: Pınar Özdemir, Hacettepe University, Sibel Güneysu, Baskent University, and Ceren Tekkaya, Middle East Technical University, Turkey pozdem@hacettepe.edu.tr

Improvement of student achievement has a long tradition in the field of science education. In an attempt to eliminate difficulties associated with the teaching and learning of Science, and to improve students' achievement, researchers have developed new approaches and theories for teaching the subject. Most of these approaches are based on learning theories that take account of differences between individuals, and one of these is the multiple intelligence theory proposed by Gardner (1983).

In order to explore the effect of multiple intelligence instruction (MII) on fourth-graders' understanding of the diversity of living things, an experimental study (Özdemir, Güneysu, & Tekkaya, 2006) collected data from 35 students in a control group taught with traditional instruction and 35 students in an experimental group taught with Multiple Intelligence (MI) strategies. While applying MII, for each lesson students were supplied seven different learning centres representing seven types of intelligence: Personal Work Centre (Intrapersonal Intelligence), Working Together Centre (Interpersonal Intelligence), Music Centre (Musical Intelligence), Art Centre (Spatial Intelligence), Building Centre (Kinesthetic Intelligence), Reading Centre (Verbal/Linguistic Intelligence), and Mathematics & Science Centre (Logical/Mathematical Intelligence). Each centre taught the same content, and students were free to study in any centre. They spent most of the instructional time moving through the centres, staying approximately 20 minutes at each centre. In this way, all students learnt each day's lesson in seven different ways.

Apart from the MI teaching strategy, during the 5-week period each group received an equal amount of instructional time and was provided with the same materials and assignments. The classroom instruction for both groups was provided by the same science teacher. The measurement instruments used as both pre- and post-tests in the study were the Diversity of Living Things Concepts Test (DLTCT) and the Teele Inventory of Multiple Intelligences (TIMI).

Independent t-test analysis showed that while there was no statistically significant difference between the mean scores of the experimental and control groups with respect to their understanding of diversity of living things concepts before the treatment, there was a statistically significant mean difference after treatment in favor of the experimental group. To examine if there was any retention, the Diversity of Living Things Concepts Test was re-administered after a further 2 months. The results of the delayed post-test also revealed a significant mean difference, between the experimental and control groups, in favor of the experimental group. These results suggested that multiple intelligence instruction produced not only better acquisition of scientific knowledge, but also better longer-term retention.

As far as intelligence types are concerned, students' responses to the TIMI showed the logical-mathematical intelligence to be the most dominant intelligence of fourth-grade students both before and after treatment. This finding is not surprising because, in classroom instruction, emphasis is typically given mainly to two intelligences, the logical-mathematical and linguistic intelligences, while the other types are generally ignored. This implies that students who are weak in either of these intelligences are usually disadvantaged.

In addition, some enhancements in the multiple intelligences of students before and after treatment were recognized, with these differences being higher in the students taught with MII, thus indicating that a multiple intelligence teaching strategy can develop students' weak intelligences. When a teacher creates an appropriate environment and guides students in a correct manner to use a variety of instructional materials representing each type of intelligence, students' interest in skills other than their developed skills might be fostered. The use of different kinds of activities including drawing a picture, composing, watching a performance, dramatizing, and playing with puzzles provided the students with a rich learning environment. Such instruction can offer opportunities for greater involvement, therefore giving students more chances to gain insights, intrinsic interest, and self-efficacy.

Multiple intelligences theory has met with a strongly positive response from many educators. It has been embraced by a range of educational theorists and, significantly, applied by teachers to the problems of schooling. It has helped a significant number of educators to question their work and to encourage them to look beyond the narrow confines of the dominant discourses of skilling, curriculum, and testing and assessment. This present study may give insights for teachers and educators about integrating the MIs into the science curriculum.

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Oscillating Reactions: Two Analogies

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Abstract

Oscillating chemical reactions are truly spectacular phenomena, and demonstrations are always appreciated by the class. However, explaining such reactions to high school or first-year university students is problematic, because it may seem that no acceptable explanation is possible unless the students have profound knowledge of both physical chemistry and mathematics. Two analogies are therefore offered in the belief that they are useful aids for facilitating some basic understanding of oscillating chemical reactions but without any mention of somewhat technical terms like "systems far from equilibrium," "self-organization," or "consecutive chemical reactions," and with no use of calculus (differential equations).

Introduction

Oscillating chemical reactions have been known for more than 80 years. Bray (1921) first informed about this peculiar behaviour in the system containing an aqueous solution of KIO_3 and H_2O_2. According to Bray, the concentrations of iodine were subject to periodic changes, and were explained in line with Lotka's (1910) (hypothetical) mechanism based on autocatalysis. Other investigators of that period were suspicious about the very possibility of the existence of "periodic reactions" and tried to offer alternative explanations (Rice & Reiff, 1927).

It was not until 1950 that another chemist, Boris Belousov, rediscovered the phenomenon, although his chemical system was completely different. It was more complex, and was based on cerium sulfate, citric acid, sulfuric acid, and potassium bromate (Winfree, 1984). This time, editors of science journals were highly reluctant to publish the submitted manuscript and suggested the need for much additional work. It was even argued that such reactions would clearly violate the second law of thermodynamics (Scott, 1995). After several years of very hard work on the issue, and another refusal of the heavily-updated manuscript, Belousov gave up attempting to publish his unique results. The phenomenon was recognized, practically for the first time, through the publications of Zhabotinsky (see Zaikin & Zhabotinsky, 1970, and the references therein), both because a decent and detailed explanation was offered and the experimental results could be easily reproduced. The oscillating reaction became world-famous and known as the Belousov-Zhabotinsky (BZ) reaction (Zhabotinsky, 1991). It might be worth noting that apart from the mentioned temporal oscillations, spatial oscillations are also possible (Walker & Winfree, 1978).

From a purely educational point of view, the BZ reaction is indeed an easy-to-perform demonstration and definitely a very attractive one (Scott, 1995; Shakhashiri, 1985; Summerlin & Ealy, 1988). All that are needed is a few grams of malonic or citric acid, potassium bromate, manganese(II) sulfate or cerium(III) sulfate, and some dilute sulfuric acid. After preparation (see Appendix A for details), the class may enjoy no less than about 100 oscillations before the chemicals are exhausted. The system oscillates between two states; the one containing Mn(IV) is brown, while the other one, containing Mn(II), is colourless (Figure 1). To some high school or first-year university students, this may look like "a kind of magic."

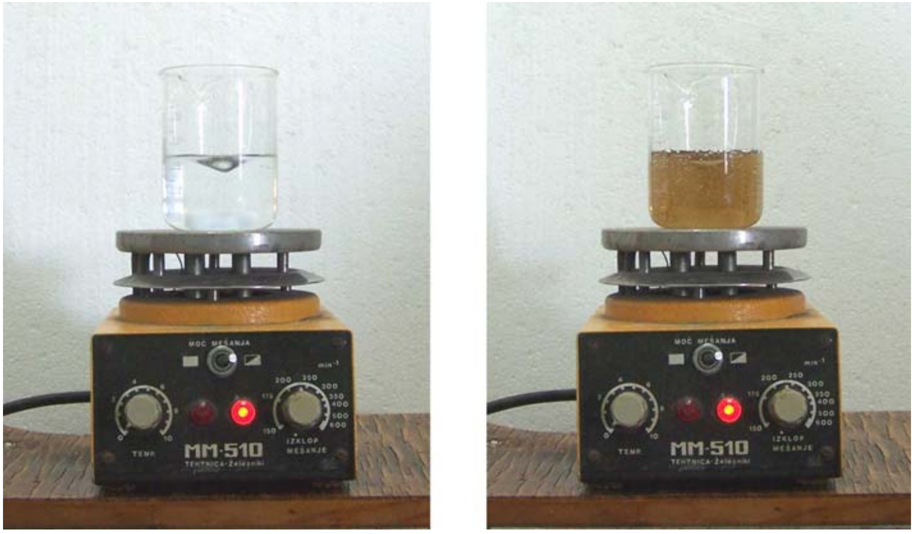

Figure 1. Colourless-to-brown oscillations of the system during the BZ reaction.

Chemistry, though, is not supposed to rely on magic; an explanation must be offered. From a pedagogical point of view, the explanation needs to be appropriate, meaning that it should be understood by the majority of the class. It might be simplified, but it must also be true. In thinking about this, we decided to offer the following two analogies.

Two Analogies

The instructor emphasizes that, in principle, in chemical reactions there exists some equilibrium mixture of reactants and products. Often, however, in the beginning only reactants are present in the system, and in the end only products remain. Such an "ordinary" reaction can be visualized by holding a sticky polymer ball 30–40 cm above a glass panel (or by using some alternative, non-bouncing combination of materials). The instant the instructor drops the ball denotes the start of the chemical reaction. When the ball reaches the glass panel and sticks to it (a fraction of a second after it was dropped), the instructor explains that the reaction has ceased. The practically instantaneous reaction of aqueous solutions of silver nitrate and sodium chloride is a good example.

The instructor further explains another type of reaction called a periodic, or oscillating, reaction. These reactions can be visualized by dropping a rubber ball, from the same height, onto a glass panel (or the floor) and noting that the ball oscillates up and down many times.

After this introduction, the instructor performs the Belousov–Zhabotinsky reaction (Summerlin & Ealy, 1988; Shakhashiri, 1985). Information is given about the chemicals used (e.g. malonic acid, $MnSO_4$, $KBrO_3$, and dilute H_2SO_4). After watching the reaction with the class for several minutes, one possible way to continue with the explanation is as follows:

> It is obvious that there are periodic changes in the system--the liquid in the beaker. Let us see, in a simplified way, what the role of each chemical is. Sulfuric acid is used to adjust the pH value (many reactions are possible only within a limited range of pH values). Potassium bromate is an oxidizing agent, and malonic acid is a reducing agent. Manganese sulfate is a catalyst. The catalyst oscillates between two states, the colourless Mn(II) and the brown Mn(IV).

The system is homogeneous (i.e., all constituents are in solution, in the same liquid phase). At the beginning of the experiment, the composition of the system is very simple (five compounds including water), but with time it becomes a rather complex one. In essence, the process taking place is a catalysed oxidation of malonic acid with potassium bromate. Since it is known that in a homogeneous system, the catalyst usually acts through formation of intermediate compounds, the brown Mn(IV) species might be identified as the intermediate. However, one still must answer the basic question: From where do the oscillations come?

To get an insight into what happens in the system, we can use a pendulum wall clock as an analogy. The wall clock is composed of a load, a pendulum, and some mechanism that enables the gravitational potential energy of the load to be transformed to the energy of the oscillating pendulum. In the case of our BZ reaction, the malonic acid–potassium bromate couple (the reactants) is equivalent to the load, the manganese (present as sulfate) catalyst acts as the pendulum, and the complex solution in the beaker is analogous to the mechanism that transforms the gravitational potential energy into energy of oscillations.

Note that the oscillations of the clock's pendulum all have the same period, while the period of the colour oscillations in the BZ reaction increases with time (with the oscillations eventually ceasing when the chemicals become exhausted). This is so because we have studied a closed system, in which the concentrations of malonic acid and potassium bromate are depleted. If we were to study the same reaction in an open system (allowing for the above concentrations to be kept constant by a continuous influx of fresh quantities of both chemicals), the BZ oscillations would also have a constant period. In this respect, the analogy with the bouncing rubber ball is an excellent one, as the energy dissipation in the case of the ball is analogous to the exhaustion of the chemicals.

When using analogies, one needs to be cautious not to extend too far the drawn conclusions. Analogies are only similarities. For a much deeper understanding of the issue, one needs a profound knowledge of both mathematics and the parts of physical chemistry called thermodynamics and chemical kinetics.

Advantages and Disadvantages of the Analogies

From our experience, this approach is a useful one for achieving a low-level understanding of the phenomenon. On a few occasions, it has proven to be a very stimulating one indeed, with several students claiming later to have decided to graduate in this field owing to the demonstration performed and the explanations offered.

The analogies provide a somewhat simplified explanation, which is why the instructor must warn the students not to make far-reaching conclusions. Instructors also often rely on a simplified approach to start lessons on the structure of the atom, for example, with first-year students. However, it is important to note that when something is oversimplified, this limitation must be pointed out in order to avoid the development of potential misconceptions.

Numerous studies (e.g., Harrison & de Jong, 2005; Orgill & Bodner, 2004; Treagust, Harrison, & Venville, 1998) have shown the usefulness of the use of analogies, stressing both their positive and negative sides. Analogies are sometimes referred to as a "two-edged sword." They help students to understand difficult scientific concepts, but if not used properly they can generate alternative conceptions. When multiple analogies are used (as in our case), the likes are strengthened and the unlikes, as a rule, weakened (as there is considerably less chance that both analogies used would lead to the same faulty conclusion). Appendix B contains a guide to help those who may decide to adopt the offered analogies and incorporate them as a tool while teaching oscillating reactions to high school or first-year university students. For those curious about the nature of the chemical changes in the system and eager to learn more of the chemistry that is behind the demonstration, the complete set of chemical equations leading to the BZ oscillating reaction is given in Appendix C.

One reviewer of the original manuscript pointed to another excellent analogy; a ball bouncing down a stair-case! In this case, each bounce brings the ball closer to the final state of rest, as in the chemical system. (One fault of both the proposed bouncing ball and the pendulum is that they pass through the equilibrium point, whereas the system subject to an oscillating reaction never passes through equilibrium.)

Acknowledgements

The authors wish to thank reviewers Richard K. Coll and Giacomo Torzo for the many valuable suggestions that have increased the quality of this paper.

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Appendix A

Experimental Procedure for the BZ Reaction

Needed. 200 mL dilute (1 mol/L) sulfuric acid, 5 g solid $KBrO_3$, 4 g solid malonic acid, and 0.5 g $MnSO_4 \cdot H_2O$.

First, the beaker containing the dilute sulfuric acid is placed on an electromagnetic stirrer and the $KBrO_3$ and malonic acid are dissolved in the acid. Once these are completely dissolved (the dissolution of $KBrO_3$ may take some 5 minutes), the manganese salt is added. The solution immediately turns brown and soon (after about 1 minute--the so-called “induction period”) begins to oscillate.

Safety hazard and disposal. Sulfuric acid is a highly corrosive chemical. When performing the demonstration, safety goggles should be worn at all times. Small quantities of dilute sulfuric acid can be flushed down the sink with a large volume of water.

Appendix B

A Guide for Teaching With the Analogies

FOCUS	**Concept**	Periodic or oscillating reactions. These may occur even in simple reaction systems and result from a series of consecutive autocatalytic reactions. The precondition is that the system is far from equilibrium, in the thermodynamic sense of the word. The changes in the composition can often be monitored visually.
	Students	Students (even those of first-year university level) are not prepared to understand the mechanism of periodic reactions, due to a lack of knowledge in both calculus and physical chemistry. They are familiar with the properties of both sticky and elastic polymer balls, and do understand the way a wall clock works, including the transformation of gravitational potential energy into oscillatory motion of the pendulum.
	Analogy 1	A sticky polymer ball is used to demonstrate the reactants (ball held in hand) and products (ball dropped on a glass surface) in an ordinary chemical reaction. An elastic rubber ball dropped on the same surface goes up and down many times, resembling an oscillating reaction.
	Analogy 2	A wall clock with a pendulum is used to demonstrate the oscillations in a chemical system. The left-to-right periodic oscillations resemble the brown-to-clear color changes during an oscillating reaction.

ACTION

LIKES - Mapping the analogy to the target

Analogy 1: Sticky & elastic balls	**Target: Periodic reactions (closed system)**
Sticky ball held in hand	Reactants: NaCl(aq) and $AgNO_3$(aq)
Sticky ball falling (fast process)	Reaction (instantaneous)
Sticky ball dropped on glass surface	Products: $NaNO_3$(aq) and AgCl(s)
Elastic ball held in hand	Reactants: $KBrO_3$ and malonic acid
Elastic ball bouncing	Oscillating reaction
Ball up	Mn^{2+}
Ball down	Mn^{4+}
The ball itself	Catalyst (manganese)
Ball at rest	Chemicals exhausted (oscillations cease)

UNLIKES - Where the analogy breaks down

- The bouncing ball touches the ground (equilibrium position), unlike the oscillating reactions that never pass through equilibrium.
- The period between successive bounces of the ball decreases (a consequence of energy dissipations). The period of an oscillating reaction (in a closed system) increases (a consequence of decreasing concentration of reactants).

LIKES - Mapping the analogy to the target

Analogy 2: Wall clock	**Target: Periodic reactions (closed system)**
Pendulum oscillates	Oscillating chemical reaction
The pendulum itself	Catalyst (manganese)
Pendulum left/pendulum right	Colour of medium: Colourless/brown
Pendulum left/pendulum right	Mn^{2+}/Mn^{4+}
Load	Reactants: $KBrO_3$ and malonic acid
Load is up	High concentration of reactants
Load is down	Low concentration of reactants
Load touches the ground	Chemicals exhausted (oscillations cease)

UNLIKES - Where the analogy breaks down
• The pendulum of the wall-clock passes through equilibrium point, unlike the oscillating reactions that never pass through equilibrium. • Pendulum moves symmetrically. No symmetry exists in the colour change. • The clock pendulum has a constant period. The period of an oscillating reaction (in a closed system) increases (a consequence of decreasing concentration of reactants).

Appendix C

Chemical Reactions for the BZ Oscillations

The system, which is initially composed of a few chemical constituents only (i.e., $KBrO_3$, H_2SO_4, $MnSO_4$, malonic acid, and water), evolves with time. The following chemical equations represent the 18 steps in the BZ reaction (Petruševski & Najdoski, 2000). The hydrated proton is consistently written as H_3O^+.

1. $2H_3O^+ + Br^- + BrO_3^- \rightleftharpoons HOBr + HBrO_2 + 2H_2O$
2. $H_3O^+ + HBrO_2 + Br^- \rightleftharpoons 2HOBr + H_2O$
3. $HOBr + Br^- + H_3O^+ \rightleftharpoons Br_2 + 2H_2O$
4. $CH_2(COOH)_2 \rightleftharpoons (OH)_2C{=}CHCOOH$
5. $Br_2 + H_2O + (OH)_2C{=}CHCOOH \rightleftharpoons H_3O^+ + Br^- + CHBr(COOH)_2$
6. $HBrO_2 + BrO_3^- + H_3O^+ \rightleftharpoons 2BrO_2 + 2H_2O$
7. $2BrO_2 + Mn^{2+} + 2H_3O^+ \rightleftharpoons Mn^{4+} + 2HBrO_2 + 2H_2O$
8. $Mn^{4+} + 2BrO_2 + 6H_2O \rightleftharpoons 2BrO_3^- + Mn^{2+} + 4H_3O^+$
9. $2HBrO_2 + H_2O \rightleftharpoons HOBr + BrO_3^- + H_3O^+$
10. $Mn^{4+} + 2H_2O + 2CH_2(COOH)_2 \rightleftharpoons 2CH(COOH)_2 + Mn^{2+} + 2H_3O^+$
11. $CH(COOH)_2 + CHBr(COOH)_2 + 2H_2O \rightleftharpoons Br^- + CH_2(COOH)_2 + HOC(COOH)_2 + H_3O^+$
12. $Mn^{4+} + 6H_2O + 2CHBr(COOH)_2 \rightleftharpoons 2Br^- + 2HOC(COOH)_2 + Mn^{2+} + 4H_3O^+$
13. $2HOC(COOH)_2 \rightleftharpoons HOCH(COOH)_2 + O{=}CHCOOH + CO_2$
14. $Mn^{4+} + 2HOCH(COOH)_2 + 2H_2O \rightleftharpoons 2HOC(COOH)_2 + Mn^{2+} + 2H_3O^+$
15. $Mn^{4+} + 2O{=}CHCOOH + 2H_2O \rightleftharpoons 2O{=}CCOOH + Mn^{2+} + 2H_3O^+$
16. $2O{=}CCOOH + H_2O \rightleftharpoons O{=}CHCOOH + HCOOH + CO_2$
17. $Br_2 + HCOOH + 2H_2O \rightleftharpoons 2Br^- + CO_2 + 2H_3O^+$
18. $2CH(COOH)_2 + H_2O \rightleftharpoons CH_2(COOH)_2 + HOCH(COOH)_2$

Readers' Forum

The Investigation Question: The Key to Successful Inquiry-Based Science?

When trying to teach using an inquiry approach, we often find that teachers and student teachers run into considerable difficulty because of the lack of a clear, single question that students are to answer. As a result, the rest of the inquiry process falls apart. We believe that often teachers confuse the making of an investigation question with the general questioning used in class, a problem confounded by textbooks, and see the need for an increased emphasis to be placed on developing appropriate investigation questions.

It is important to identify what makes a good investigation question and what doesn't. An investigation question should aim to answer one specific, easily answered question. There is no value in having students trying to answer questions by needing to discover general theories such as natural selection or relativity!

For example, consider the question: Why does pondweed produce bubbles? This is a very poor investigation question. Can you think of a way to design an experiment to answer it? To answer this question, students would have to either have prior knowledge about photosynthesis or do some background research. However, by changing the question slightly it can be made much better: What effect does temperature have on the bubbles coming from pondweed? This question is much more direct and aims to answer one specific problem. Students will find it much easier to design an experiment to answer this question.

Consider these questions and ask yourself whether you could design a simple experiment to try to answer them: How does the heart work? How do mice behave? What are trees like? What is density? Why do candles burn?

Now look at the following questions about the same topics, but questions that are more specific and aim at posing a simple, answerable problem: What effect does exercise have on your heartbeat? Can mice see colours? Do different kinds of trees have different heights? How well do objects of different density float? Do candles burn slower when it is cold?

Can you think of ways to try to answer these questions? These are the types of questions that make ideal investigation questions, allowing students to design investigations independently and in an inquiry-based way. Unfortunately, we often find teachers using the first type of question as the basis for experimentation in their inquiry lessons.

Teachers may be confusing the making or posing of an investigation question with the general questioning that they use throughout a lesson. Often the distinction between these two kinds of questioning is not clearly made in textbooks about inquiry-based science. These texts often vaguely say that questioning is important in the inquiry-based science classroom, but without explaining whether they mean the formulation of an investigation question, a teacher's general classroom questioning, or both.

We suggest that the distinction between investigation questions and the general questioning used throughout an inquiry lesson should be more clearly made by the science education community. Teachers should be made aware that the question they use as an investigation question needs to be a specific, answerable one and be shown how to identify and develop good investigation questions of their own. Without this, inquiry will fail.

Kirsten Schlüter and Mark Walker, University of Siegen, Siegen, Germany

? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

Teaching to Learning Styles

Olson (2006) has recently concluded that teaching towards students' preferred learning styles is unproductive, and can even be detrimental. Does anyone feel in a position to respond to the content of this article? (*Editor*. Olson's article is summarized on p. 65 of this issue.)

Reference

Olson, J. K. (2006). The myth of catering to learning styles. *Science and Children*, *44*(2), 56-57.

In my view, the idea of learning styles is not to teach exclusively to students' preferred learning styles. In the first place, it's impossible if you have more than 2 students in a class--there's no practical way to individualize instruction to that extent. Even if you could do it, though, it wouldn't be desirable. The goal should be balance, making sure that you don't exclusively address the needs of one learning style category and neglect its opposite. To be effective as professionals--in any profession--students need to develop skills associated with each category of every learning style dimension--sensing and intuitive, visual and verbal, etc. If you teach them in a style heavily mismatched to their preferences, they will probably be too uncomfortable to develop many skills at all. On the other hand, if you teach them exclusively in the manner they prefer, they may be happy about it and will develop skills associated with their preferences, but they will never be forced to stretch and develop the skills associated with their less-preferred style categories. You can find out more about all this by visiting Felder (n.d.) and clicking on the Learning Styles link, perhaps starting with the paper "Matters of Style."

Reference

Felder, R. (n.d.) *Resources in science and engineering education*. Retrieved April 12, 2007, from www.ncsu.edu/felder-public .

Richard Felder, North Carolina State University, Raleigh, NC, USA

In light of the argument presented by Olson, the short, explicit, and logical answer to the question "Do 'kinesthetic learners' really need kinesthetic activities in order to learn" (p. 56) presented in the introduction to her article would obviously be "No." I do not wish to question the general conclusions of Olson or the authors she cites. However, upon careful reading of the paper and references, I note that no mention of children's motivation has been made, and this seems to be of potential importance.

Personally, I am inclined to believe that accommodating the preferred learning style of a subject may result in a significant increase in his or her score, in some cases at the very least. I will give two examples. When I was in the 7^{th} or 8^{th} grade (i.e., in my medium school), I was attending for several years a separate music school, where I had lessons on piano, "solfeggio," and music theory. Many of us had perfect (or almost perfect) pitch, thus having no problem hearing whether the accord played is c- (consonant) or d- (dissonant). A few students were far from being talented, and it was impossible for them to tell even the notes in the accord, let alone whether they were c- or d-. Still, they could easily judge the type of the accord, providing that the notes were written in their music notebooks, because the rules are really simple (like counting the number of half-intervals between two notes). Obviously, for those lacking a musical talent, the "natural" way of teaching music gives poor results. However, the "unusual" approach of writing the notes lead to success. Surely, these students could hardly become famous singers or instrumentalists, but the point is that tailoring the instruction in such a way as to avoid their lack of pitch did work!

The other example comes from my tennis lessons and happened roughly during the same period (~ 40 years ago). Unlike nowadays, a top-spin was used rather seldom. The coach used his standard approach: He performed several top-spin shots, and then patiently explained what he was doing and why, explained the fast rotation of the ball, explained what part of the racket was used and why, etc. Being a visual guy (like most of the others in the group), I realized what I was supposed to do and practiced for many days. The results were, I have to say, modest to poor (frankly I never learned it properly). A few of the other guys did it terribly wrong! After a couple of days, the coach was sick of all those balls being launched in all possible directions and tried another strategy: He would grab the guy's hand with his and guide the subject's arm and hand, first slowly then faster and faster. On two occasions, terrific progress occurred, with one of the guys proudly announcing: "I felt how to 'do' the ball with the wrist." I did not know the word at that time, but obviously this subject was a kinesthetic learner. Needless to say, in a few days both guys built superb forehand top-spins, although this approach didn't work with me.

So, the above examples seem to suggest that, on certain occasions, the answer to the question "Do 'kinesthetic learners' really need kinesthetic activities in order to learn" should be "Yes," and that tailoring instruction to the preferred learning style of a subject might be beneficial. And if this is true in music and sports, I can see no reason why it should not work in the sciences.

Vladimir M. Petruševski, Sts. Cyril & Methodius University, Skopje, Republic of Macedonia

As a current teacher of Science to students in Years 7-10, I would agree with the basic premises outlined in the article. I would categorise myself as an experienced teacher, so an immediate response would be that this is nothing new and that's what I strive to do anyway. However, upon further reflection, I would suggest that this would be useful reading for a teacher-in-training; it would provide a useful background to help analyse lessons being observed.

Scaffolding and fading would be a bedrock strategy to help lead students from the concrete through to abstraction, and also as a means to develop the basic skills required for scientific, inquiry-based investigations. A diverse range of activities to support this pedagogical approach is necessary in order to enable more students to grasp the concepts being presented.

The principles underlying the theory of Multiple Intelligences suggest we all have preferred learning styles and thus learn better using these. Perhaps this leads to a strengthening of those skills.

Guy Claxton's *Building Learning Power* (2002) enables the identification of our learning strengths and weaknesses. Incorporating his "learning capacities" into a teacher's pedagogy offers a broad spectrum of learning experiences for students.

Remaining in a comfort zone of preferred learning style may not "stretch" a learner, nor challenge them to higher-order thinking; they could become inured to possibilities or learning opportunities. (Perhaps the old maxim, though, of "leading a horse to water but not being able to make it drink" may apply in the case of some students.) However, some disengaged students can only become productive learners when the activities match their learning style.

Classes may sometimes be homogeneous in terms of student ability. However, I would suggest they would rarely, if ever, be homogeneous on the basis of multiple intelligences. Anecdotally, time has shown me that the greater the diversity of learning experiences, the more involved all members of a class become; they will more readily attempt activities outside of their comfort zone.

In this current climate of personalising learning and differentiating the curriculum, carefully designed major tasks incorporating a variety of skills often lead to improved learning outcomes. (In this sense, scientific investigation incorporates a diversity of skills.)

Reference

Claxton, G. (2002). *Building learning power: Helping young people become better learners.* Bristol, UK: TLO.

Noelene Wood, Ogilvie High School, Tasmania, Australia

From a postmodern perspective, dispelling myths about anything is quite crucial. Dispelling myths about learning is more than welcomed, given that such myths can provide guidance to educators and teachers that may very well restrict, rather than promote, opportunities for learning. It is from this perspective that Olson provides science teachers and educators with some "food for thought." However, having said this, I would like to stress that, while Olson's article dispels a myth about the importance of relying heavily on styles, the role of learning styles in the learning process should not be rejected.

Ever since Carl Jung published his work on psychological types in the 1920s, the idea that people perceive reality and process information (gathered from that reality) in various ways has been quite useful, since we can explain and understand individual differences in connection with anything we do, including learning. In other words, it makes sense to use Jung's theory (in placing primacy on the notion of personality) as a basis for designing learning models. However, one question needs to be posed: Can Learning Style Theory (LST) be considered the major, or best, way toward designing more effective science teaching/learning (T/L) models?

In recognizing the complexity of the learning process, it would be more than naïve on anyone's part to believe that there is a single, most important factor influencing learning. This means that designing T/L models based on that factor would be equivalent to misunderstanding the learning process itself. In this sense, Olson is right in drawing our attention not just to prior ideas--which we believed for more than 3 decades to be the single most important factor in learning science (according to Ausubel's exhortation)--but also to how the subject matter (content knowledge) can be best represented, and to the analogies we can use to make some abstract ideas understood (I think Olson's paper implies such an idea).

But the idea that learning styles can in some way be incorporated to our T/L models, along with what Olson recommends, should also be considered. In acknowledging, of course, some important limitations of Learning Style Theory, and more specifically the fact that it does not consider a) the context and b) the content of learning, we should nevertheless consider the motivational factor behind learning styles. Certainly this motivation to learn, derived from the opportunity one has to use one's preferred style of learning, is not a crucial factor determining learning, according to research cited by Olson. This, of course, strengthens my initial point; namely, that the learning process is a complex one, in which several factors are at play. Two such factors are purposes and expectations one has for learning. In actual fact, these two notions have been central to Identity Theory, which has provided the theoretical framework for some recent studies in science education. These studies have provided evidence that learning science is not just a matter of acquiring, or constructing, knowledge but is also a matter of deciding what kind of persons students are and what they aspire to be. In other words, the expectations and the purpose one has for learning something may very well be a much stronger motive than that derived from the opportunity one has to use one's preferred style. The construction of personal meaning, and not just of conceptual understanding, is also a factor that needs to be addressed in planning instruction. Worldview Theory, I would say, may be a better framework (in comparison with LST) on which to base instructional design.

So, in conclusion, I would say that Olson has certainly raised an important point regarding the danger--if I may use such a word--of relying heavily or exclusively on LST in order to promote learning. She has also made worthy recommendations concerning science teaching and learning. In this sense, she has told us some truths, but perhaps not the whole truth. What I mean is that I would be careful not to interpret her paper as a rejection of the value of LST. So I would recommend that we strive to find ways to include LST in our T/L models. For example, Multiple Intelligence Theory (which takes into account the content of learning) may be integrated with LST. More holistic models, like the 4MAT model, and more holistic theories like Worldview Theory, are also welcomed. And, of course, if there is strong evidence that a person does have a dominant learning style, it would not be a good idea to not consider it when planning and delivering instruction.

Yannis Hadzigeorgiou, University of the Aegean, Rhodes, Greece

Olson’s article conflicts with what we know so far about learning styles, and is very open to discussion. Many experimental studies, with well-controlled variables, would be needed before reaching such conclusions. Generally, we do not agree with the thrust of Olson’s article.

Numerous studies have demonstrated the benefits of accounting for learning styles while learning. To give an example, Dunn, Griggs, Olson, Gorman, and Beasley (1995) conducted a meta-analysis of 42 experimental studies conducted across the United States at 13 different universities during the 1980s. Regardless of the researcher, the university where the research had been conducted, the students’ grade level, or the element(s) examined, that analysis revealed that students' learning style preferences were the strengths that enabled them to master new and difficult information. For instance, the data from the studies conducted at every level of many institutions of higher education (O'Hare, 2002; Rowan, 1988; Russo, 2002) documented that when academic underachievers were taught new and difficult (for them) content through instructional approaches that responded to their learning style strengths, they achieved statistically higher standardized achievement test scores than they did when the approach was dissonant from their style (Dunn, 2003; Dunn & DeBello, 1999).

Further, there are many other variables to consider before arriving at the conclusion of Olson, such as the nature of the subject matter, the learning styles of the teacher applying the learning styles models in the classroom, and the previous knowledge that students have. Learning styles develop children's innate potential rather than their ability to master extraneous academic information. Therefore, without considering the learning styles of students in a correct manner, knowledge acquisition would not be meaningful, thus contradicting the ideas of better learning. We therefore see that the number of studies demonstrating that teaching based on students’ learning styles improves both classroom success and satisfaction (Griggs, 1992; Klavas, 1989; Thomson & Mascazine, 1997) are far more numerous than the studies cited in Olson’s article, and we must not overlook these other studies and ideas.

Teaching toward students’ preferred learning styles has a solid basis in research in that, especially since the 1970s, much research conducted on the issue has emphasized the importance of considering learning styles. We agree with the idea that using appropriate representations that carefully consider how to convey the content is important. However, this leads us not to the idea of not considering learning styles but to the use of learning styles based appropriately on the content. Actually, there is not any single teaching method, including learning styles, that is best for all of the subject matter that would be implemented in class. We cannot select and use only one method in all our science classes. Decisions about the teaching method that we use in a class should be based on various issues. Content is only one of these variables, and we must give importance to the others, including the students' learning styles. Otherwise, by considering only a learning style based on content, we may not get any positive results, because the learning style may not be suitable for the majority of students in the classroom. Olson's idea conflicts in itself, since there is a generalization based on a narrow range of studies. If not used appropriately, of course, every teaching method leads to lower achievement. If the content, the nature of knowledge (new or difficult), or the students' level of knowledge are not compatible with the instructional approach, then students receiving instruction in their preferred format might exhibit overconfidence in their ability to learn and invest less effort in learning the content. The crucial point to consider, therefore, is to select the most appropriate teaching method by considering all of the variables involved. Furthermore, to use the style that best suits the content being addressed, without regard for students' preferred learning style, will not be beneficial. The reason for this is that I think it is basically more important to consider learning from the point of view of students than content. Instead of relating the learning styles with the content, we must relate the content with the appropriate teaching method. Also, when we relate the content with the suitable teaching method or strategy, we should not only consider the learning styles but also the individual differences. Therefore, more importantly, we should find ways to include the majority of students into the classroom. One of the ways of achieving this is to take the individual differences of the students into consideration while preparing lessons. The point is to be aware of the differences among students, one of which is learning styles, and to consider these in our lessons.

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Reply by Joanne K. Olson, Iowa State University, IA, USA

I appreciate the discussion regarding the issues I raised in my article. I'll preface my response by indicating that the journal in which the article appeared, *Science and Children*, had a strict word limit and, as a result, it was necessary to omit many important scholarly contributions in this area. The issues I communicated to the science education community are those being raised by cognitive psychology researchers who have been concerned about how learning styles are being embraced and implemented in the education community, despite the lack of empirical evidence to support such approaches. Clark (2005) summarizes the situation as follows:

> Adjusting instruction to accommodate different learning styles or "multiple intelligences" simply does not work. For example, different types of instruction for

> "visual" or "verbal" students have no impact on learning. The Myers-Briggs Type Indicator test is neither reliable nor valid and we have no evidence that multiple intelligences exist or can be used effectively in teaching. While learning styles are intuitively appealing, 50 years of research on them has resulted in the same negative findings. (p. 16)

Clark's sentiment is echoed by fellow cognitive psychology researcher David Willingham (2005):

> The possible effects of matching instructional modality to a student's modality strength have been extensively studied and have yielded no positive evidence. If there was an effect of any consequence, it is extremely likely that we would know it by now. (p. 33)

Research consistently shows no effect when matching instruction to students' preferred learning style (Arter & Jenkins, 1979; Kampwirth & Bates, 1980; Mayer & Massa, 2003; Salomon, 1984; Stahl, 1999). When Kavale and Forness (1987) conducted a meta-analysis and focused on studies that met important criteria for isolating the variable of learning style, they found no positive effect. Those who support the matching of instruction to students' preferred learning styles usually cite the work of Dunn and her colleagues (e.g., Dunn, Griggs, Olson, Beasly, & Gorman, 1995). However, her work has been harshly disputed in the literature. Kavale, Hirshoren, and Forness (1998) criticized her meta-analysis because almost none of the studies she analyzed were subjected to external peer-review. Willingham (2005) points out that all but one of the studies in Dunn's review were unpublished doctoral dissertations, and 21 were from Dunn's home institution. Willingham claims that her study is "hard to take seriously" (p. 44) due to the risk of confirmation bias that arises when research teams design and conduct numerous studies without external, impartial, expert reviewers. An excellent overview and analysis of decades of research in this area is provided in Kavale and Forness (1987). A more recent review, conducted in 2005 by a United Kingdom think tank, can be found at *Demos* (n.d.).

Motivation, discomfort, and learning. Motivation is certainly a crucial factor that affects learning. Intuition leads us to believe that matching instruction to a student's preferred learning style would lead to an increase in motivation, and therefore to an increase in learning. However, the opposite is the case. Salomon (1984) found that students exerted less effort to learn when the instruction was matched to their preferred style. Those students performed significantly worse on tests of the material than their counterparts who had been in a classroom setting where their learning styles were not matched. Despite common intuition that students should be more motivated when the task is matched to their style, their effort (a key component of motivation) actually decreases. For an informative resource on motivation and its many components, see Pintrich and Schunk (1996) or Eccles and Wigfield (2002).

So, research indicates that too much comfort decreases effort, and consequently decreases learning. This finding is not new. Joyce and Weil (1996) address this issue when describing a study by Hunt et al. (1981):

> Curiously, the more a given model of teaching was mismatched with the natural learning style of the student, the more it presented a challenge to the student to take an affirmative stance so as to pass through the period of discomfort and develop skills that would permit a productive relationship with the learning environment. (p. 389)

Educators frequently seek to make students comfortable, but Joyce and Weil (1996) point out that:

> Rogers (1956) also emphasizes that our natural tendency as learners is to confine ourselves to domains in which we already feel safe. A major task of counselor/teachers is to help the learner reach into those domains that are shrouded in fear. To grow, learners have to acknowledge discomfort and set tasks to help break the barriers of fear. (p. 389)

Not surprisingly, in Hunt et al.'s (1981) study, students "pulled" teachers' behavior toward their preferences. An important balancing act that teachers must constantly consider is how to make the environment socially comfortable enough for students to participate and contribute ideas, but intellectually uncomfortable enough for students to optimally grow without being overwhelmed.

Problems with instrumentation and student self-reports. All of us should take seriously the concerns that are being raised by the cognitive psychology community about the validity and reliability of instruments designed to assess students' learning styles (Duff & Duffy, 2002; Henson & Hwang, 2002; Kavale & Forness, 1987; Loo, 1997; Richardson, 2000; Stahl, 1999). Student preferences and self-reports of learning are highly problematic. As Clark (2005) points out: "In a significant number of instances, the more students think they learned from instruction, the less they actually learned. This occurs most often when students believe that instruction has made learning 'easier' and/or when they are in 'minimally guided' settings" (p. 16). Bernard et al. (2004) conducted a meta-analysis and found that student interest was inversely related to achievement. When provided choices, "learners often selected the instructional formats that were least helpful for their achievement" (Feldon, 2005, p. 38).

"Learning styles" vs. "traditional Instruction." Students often appear to do better when we "mix things up" in the classroom not because we are matching their learning style, but because we are more likely using a representation that is better suited to the content under study, or because the representation is more concrete and thus easier for the learner to grasp. Studies that compare matching learning styles with "traditional instruction" often show that the students in the "learning styles" classroom do better. What is crucial to consider is that almost any instructional method will show positive results when compared to traditional instruction. Traditional instruction is typically so discordant with how people learn (by placing abstractions such as talk and text prior to, or in place of, experiences), that anything using a more concrete representation early in the experience will likely work better.

Variety for its own sake? Willingham (2005) notes: "Experiences in different modalities simply for the sake of including different modalities should not be the goal. Material should be presented auditorily or visually because the information that the teacher wants students to understand is best conveyed in that modality" (p. 35) While some see the use of variety in the classroom as an end worth pursuing to avoid student boredom, variety for its own sake can result in representations that make little sense to students, such as the recommendation to spell words with twigs and leaves--apparently to appeal to those with a "naturalist intelligence" (Armstrong, 2000). When we carefully consider our content, as well as the developmental needs and background knowledge of our learners, students will work with a variety of representation types as a natural consequence, because the subject matter we teach necessitates it and because we are considering our learners' readiness.

Why does learning styles seem so correct? Willingham (2005) notes that catering to learning styles is an intuitive notion that seems supported by experience, despite consistent research that indicates otherwise. It appears to account for students' differences, and it appears to account for teachers' experiences with students. When a student struggles and the teacher tries a different way to represent the concept, such as a drawing, the teacher may easily interpret the student's new understanding as due to a previous learning style mismatch, and the match of the new representation. But the new understanding is accounted for by a number of other explanations, such as the drawing being better suited to the content, the drawing being more concrete, and the drawing better triggering a similar memory in the student's prior knowledge. The problem with using personal experience (either our own learning or our own teaching) as support for catering to students' learning styles is that such approaches are not supported by decades of research, and our own self-reports and intuition about learning are often wrong (Clark, 1982; Feldon, 2005; Shulman, 1986). An important advantage of research is that it "sometimes provides counterintuitive evidence and so prevents us from unintentionally causing damage or investing scarce resources in instruction that does not support learning" (Clark & Feldon, 2005, p. 114). Dewey (1929) pointed out that education is open to fads, gurus, and other "quick fix" promises when we fail to consider research when trying to solve educational problems. We would be wise to heed his warning.

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Laboratory Safety Guidelines

This section presents a series of 40 laboratory safety guidelines kindly provided by Dr James A. Kaufman, President, The Laboratory Safety Institute (LSI), USA. Please visit http://www.labsafety.org for further information, products, services, and publications.

#2 of 40. *Organise a Safety Committee*

Your department should have a safety committee. Academic institutions and companies should all have safety committees. The committees should comprise employees, supervisors, faculty, staff, administration, and students.

The committees should meet regularly to discuss safety and health and environmental concerns/problems and to seek solutions to them. The committee should help to see that the safety policy is implemented. The committee can help to promote an interest and concern for health and safety issues. They might be the group responsible for conducting regular inspections, reviewing accident reports, and developing recommended safety procedures. Better is to be a coordinating group that engages all the other employees in the organization in these activities.

One type of safety committee is the central safety committee. It is chaired by the highest-ranking onsite official. The members of the committee are his or her direct reports. In this way, senior management/administration is involved and providing leadership in the safety program. The central safety committee is the way they do it at DuPont. For more good ideas from DuPont, read *Excellence in Safety Leadership* by James Thomen, available from LSI.

How often does your committee meet? Once a year? Quarterly? Every other month? Monthly? More is more! What responsibilities does your safety committee have? How well does the committee work? What problems do you have? Please send us a list to share with others.

Further Useful Resources

The Flying Circus of Physics (2nd Edition, by Jearl Walker, published 2007 by John Wiley & Sons). This expanded collection of natural phenomena and physics oddities, in question-and-answer format, now also features fascinating short stories scattered throughout the chapters. While the answers include no equations, an extensive set of references, marked as to mathematical difficulty, is now provided at www.flyingcircusofphysics.com .

Uncovering Student Ideas in Science: 25 Formative Assessment Probes (Vol. 1) (by Page Keeley, Francis Eberle, & Lynn Farrin, published 2005 by NSTA Press [National Science Teachers Association, United States] http://www.nsta.org/). Short activities, for use at the start of a topic, to determine what K-12 students think they know about a range of physical, life, earth, and space science topics. Use the results to adjust teaching accordingly. Each probe is accompanied by teaching materials that include an explanation of the science content, a summary of relevant research on learning, and suggested instructional approaches.

Planet SciCast (http://www.planet-scicast.com/) Short movies of science demonstrations, including a competition.

Vega Science Trust (http://www.vega.org.uk) Videos of scientists discussing important scientific issues. To also be available soon on DVD.

Computational Science Education Reference Desk (CSERD) (http://cserd.nsdl.org) A catalogue of lessons and tools for teaching with computational science, the art of using computers to perform the mathematics behind modern science.

Pre-test and Formative Assessment Resources

Force Concept Inventory (FCI) (http://modeling.asu.edu/r&e/research.html)
Diagnoser Tools (http://www.diagnoser.com/diagnoser/index.jsp)
Field-Tested Learning Assessment Guide (http://www.flaguide.org/intro/intro.php)

SETI@home Project (http://setiathome.berkeley.edu/) A scientific experiment that uses Internet-connected computers (e.g., those of students) to process data, captured by the Arecibo radio telescope in Puerto Rico, in a search for extraterrestrial intelligence (SETI).

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