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Contextual Settings, Verbal Argumentations, and Science Stories: Toward a more Humanistic Science Education.

Introduction

Today's constructivists see learning to be context-bound, and emphasize domain specific knowledge structure. Moreover, they see learning as an adaptive process in which the learners' conceptual schemes are progressively reconstructed in keeping with a wider range of experiences (Driver, 1989). Knowledge is thought to grow through a process of equilibration and knowledge schemes confronting new experiences. It seems that children may progress in their understanding of science concepts by way of intermediate notions that, although pre-scientific, are necessary precursor to understanding organized scientific content knowledge (Osborne, 1984)

It is a truism that appropriately designed contexts which attract young students' interests often create great motivation to learn science. However, setting appropriate contexts go beyond serving as a source of motivation. There is strong evidence that we must connect cognitive activity to context, that learning methods embedded in context are not merely useful; they are essential (Roth and Roychoudhury, 1993).

Experienced teachers know that before they can expect students to consider the learning of science interesting and relevant, they must ensure that a number of conditions are satisfied. First, teachers must plan the context in a way that ensures that the questions and the problems that are generated from the context capture the students' interest, that they seem "real" and make sense to them. Secondly, teachers should keep in mind that for a contextual setting to get off the ground at all, students must be able to, at the beginning, answer a few basic questions and solve a number of problems with little effort. Thirdly, teachers should try to prepare students to face questions that they cannot answer easily, with a measure of enthusiasm and confidence. Finally, experienced teachers try to avoid questions that require quick, glib answers taken from readily available references. Teachers know that group discussions, guidance and plenty of well sequenced concrete activities are essential in motivating young students to learn new relevant content, but always expressed in the students' own language (words).

Can we reorganize the science curriculum around contexts and science stories that serve to motivate students, to help them learn science conceptions "naturally", and to develop understanding that is rooted in the scientific and in the humanistic traditions? This question frames one of the central problems of science education, namely, how to help children and students achieve an integrated view of the world based on personal knowledge of science that is not disconnected from the humanities.

I will argue that to provide such an integrated view of the world we should develop and use special kinds of contexts based on students' experiences and interests. For the middle years I will recommend the use of science stories based on history as well as the design of special contextual settings. In the senior years I will outline special story-like approaches as well as a specific contextual setting that I call large context problems (LCPs). My argument for a curricular revision are based on the following two assumptions:

a. Diverse connections between the sciences themselves and with the humanities are best established in multidisciplinary contexts using verbal arguments, science stories, story-like approaches, and large context problems, and

b. Presenting the content (and processes) of science that is first guided by an appropriate model of conceptualization and later imbedded in the contexts of inquiry, is superior to textbook-centered teaching of science.

The Content-context problem in science education

A general problem then emerges whenever teachers try to escape from textbook-centered teaching to teaching science by way of contexts that students find attractive: *In order to answer the questions and solve the problems generated by a context students already have to have mastered a considerable body of content.*

The interaction between content and context then presents a central pedagogical problem. We could summarize the problem this way:

To motivate students to acquire content knowledge we set contexts that attract them. However, students cannot deal with the questions and the problems that the context generates unless they already have some content knowledge.

The traditional way out of this dilemma is simply to present the organized content knowledge of science as early as elementary school. Such concepts and conceptions as energy and energy transformations, photosynthesis, atomic structure, DNA, and kinetic molecular theory are often introduced between grades two and six. However, young students are not ready developmentally for these concepts of organized science content knowledge. We must, therefore, try to ease the passage of children from early apprehension of the world, to personal scientific knowledge rooted in language, to a comprehension of organized scientific knowledge. One plausible approach to achieve this might be early introduction to science by way of contextual teaching that connects with students' personal experiences and contemporary issues of interest to them. Students should then participate in group discussions and experiential and experimental activities, encouraged to explain everyday phenomena *in their own words*, and be given plenty of opportunities to engage in personal reflection. In other words, in confronting the questions and problems the context generates students should offer their own verbal descriptions and explanations. It is here that the early and middle years student will be able to make connections with other contexts and develop "low level schemata" for decontextualizing and generalizing scientific knowledge.

In a recent study of how students generate explanations in middle school Wong (1993) attempted to "develop a means by which, students evaluate and modify their own explanations for scientific phenomena with minimal subject-specific guidance from the teacher". He explored the potential of student generated analogies for advancing conceptual understanding. Such analogies can be seen as one class of "low level schemata" that make new situations familiar and "stimulate abstract thinking about underlying structures or patterns". In addition, Strube (1989) claims texts in science "may not be meeting their purposes to instruct, due to their over-riding concern to *'inform'*, and therefore do not develop a language of inquiry appropriate to the student. This tendency of text to 'inform' only is especially damaging in the early and middle years since there is no provision made for the student to explore problems that are interesting, nontrivial and personally relevant to the learner (Wong, 1993). Finally, Glassen and Lalik (1993) have used what they call a Language-Oriented Learning Cycle for middle school science that has an exploration, clarification and elaboration cycle. This cycle uses verbal argumentation, among other approaches, that allow students and teachers negotiate the meaning of scientific explanations.

The senior years student should go further and be able to generalize and make connections between contexts and organized scientific knowledge. These connections should be made using verbal arguments that involves personal knowledge as well as the language of decontextualized science. For example, the senior physics student should be able to give a well reasoned, well written explanation of the notion of 'weightlessness' inside the orbiting space shuttle. It is clear, however, that students will not learn how to provide (and will, indeed, be reluctant to do so) such an explanation unless teachers stress verbal argumentation and "assign scientific explanations a prominent place in science classrooms..."(Dagher and Cossman, 1992).

This act of generalization, however, often amounts to an epistemological break with common sense and the everyday world. For example, physics teachers try to persuade students to escape seeing the world of motion in Aristotelian terms to understanding motion in Newtonian terms. As physics teachers well know, such a break is difficult, and can be compared to a paradigm shift. Referring to such shifts Champagne and others have concluded that: "Paradigm shifts are not accomplished easily, neither in the scientific enterprise *nor in the minds of students* (italics mine)" (Champagne et al, 1980, p. 1074).

Our goal then is to postpone the formal, decontextualized imparting of organized science content, or "scientists' science", until the students are able to demonstrate a readiness for it. I believe that teachers can assess students' level of readiness for "scientists' science" by identifying their "low level schemata", or what could be called *decontextualized scientific knowledge on the personal level*. However, the students must be able to make these schemata explicit by clearly describing phenomena and generalizing across contexts, expressed in their own words.

Our aim should be to have students say, when they finally encounter such products of organized scientific knowledge as

photosynthesis, *Newton's second law* or *the law of definite proportions* formally: "I understand, it makes sense", or "I remember: this is like...", or even: "Of course, how could it be otherwise?"

Contextual teaching in the early and middle years

My science education students have designed two types of contextual settings that can be used in the early and middle years. These are historically based science stories and contexts that deal students' experiences and contemporary issues of their interest. I will discuss science stories in some detail now, but only indicate the nature of contextual teaching in the early and middle years . The features of and guidelines to contextual teaching in general will be discussed more fully later.

Textbooks often tell brief science stories that celebrate the moment of creative insight, commonly known as the "aha-experience". The paradigmatic example of such experiences, of course, is Archimedes' discovery of the law of flotation.

My science education students have also written many science stories based on the circumstances surrounding a celebrated moment of discovery. A group of us are now involved in a multimedia project, appropriately entitled "Eureka Project" where we dramatize the discovery of the three laws of physics known to the Greeks (the law of reflection, the law of flotation, and the law of levers). The science of the Greeks, because it is essentially high-grade thinking based on unaided observation, seems especially well suited for teaching early years and middle years science.

Indeed, timing may be important in introducing to the student concepts and experiments in science. In fact, one can argue that the "teachable moment" of the historical context in science is precisely at this time (6-14 years) and perhaps again in graduate school. If we introduce them too early we will encounter problems because intellectually students are not ready. If we introduce them too late "children's science can ossify into layman's science,...showing little or no motivation to change their present view" (Osborne *et al,* 1984). Science teachers in high school know that it is very difficult to teach science in historical context because, as Kuhn has pointed out, "students (senior high school) know what all the answers are" (Kuhn, 1962). .

The vignette of depicting the moment of insight, of course, does little to contribute to our understanding of the scientific creative process. However, a good understanding of the events and the ideas that, at least in retrospect, made that event seem almost inevitable, is probably necessary for our complete understanding of the creative element in science. After all, there must be a prepared mind before a discrepancy that elicits a genuine "aha-experience" can be sensed.

Clearly, science stories incorporate a "scientific element" and a "humanistic element". We have found that even the simple telling of such stories as "Archimedes' Adventures", and "A Day in the Life of an Alchemist", the crafting of the story is a humanistically creative process.

Finally, contexts should be developed that relate to students' current experiences about the world around them and to ideas and issues that interest them. Such topics as "The color of the sky", "Solar cooker", "Electricity in the Home", "Spaceship earth", "Black Holes", "Star Trek Space Travel", "Bionics", "Electromagnetic Levitation", The Safety of Nuclear Plants"

suggest contexts that teachers can develop. I will discuss the detailed mechanics of designing such contexts below.

The large context problem: contextual teaching in the senior years

The superiority of a contextual approach over textbook-centered teaching in science (physics) became clear to me after designing and successfully using my first large context setting for a senior physics class. What I later came to call the large context problem (LCP) approach was originally developed as a response to the discovery that *learning could be well motivated by a context with one unifying central idea capable of capturing the imagination of the students.*

In my experience contextual approach to the teaching of physics may be more time-consuming then the conventional textbook approach. However, the understanding of the student as well as the quality of interaction between the student and the teacher is lifted from an ordinary to a high-grade level. Examples of early large context problems can be found in the literature (Stinner, 1973, 1980 a, 1980 b., 1981, 1989 a.).

The design of science stories and LCP's.

So far I have only suggested the design and the proper placing of science stories and of contexts such as the LCP. I will now spell out the guidelines, which evolved over the years, that my science education students use in developing contexts and in drafting science stories and LCPs. Since the prototype context for which these guidelines were first given was the LCP I will briefly touch on those features of the process that led to these guidelines.

For each given major topic in physics, such as kinematics, several LCPs for the teaching of high school physics were developed. The student of physics chooses one LCP that attracts his/her imagination. However, each LCP must be so designed that *all* of the physics for a particular topic is used for the successful completion of the problems suggested by the context. What is so attractive about this kind of setting is that the problems are generated naturally by the context and will *include* problems that are artificially given out of context in a textbook for a similar topic. Moreover, physics students' responses to the LCP approach suggest that they should be designed by the instructor. Indeed, ideally, LCP's should be designed cooperatively by students and the instructor. Such a cooperation gives both the instructor and the student the status of researcher and the feeling of participation in an on-going research program.

Teachers, of course, have used similar approaches in the past. The design of simple mechanical contrivances to perform some task would be one kind of large context problem. Tinker toys or erector sets are an excellent medium for doing large context problems. The *mechano sets* of the post-war period and

Legos used by today's children are well suited for creating LCPs for a children. These settings then become the student's first significant and organized *hooking on to an aspect of the world of his/her choosing*, in what Whitehead (1967) calls the *stage of romance*. This stage provides the setting for problem solving, or what Whitehead calls the *stage of precision* and involves the systematic organization of these fragments.

In my own science education classes at the University of Manitoba I have had students design LCPs as well as "science stories", for science in general and physics in particular for the last three years. The following guidelines have evolved over the years for the design of such contexts:

1. Map out a context with one unifying central idea that is deemed important in science and is likely to capture the imagination of the student.
2. Provide students with experiences that can be related to his/her everyday world as well as being simply and effectively explained by scientists' science, but *at a level that "makes sense" to the student*.
3. Invent a "story line" that will dramatize and highlight the main idea. *Identify an important event associated with a person and find binary opposites, or conflicting characters or events* (Egan, 1987) may be appropriate here.
4. Ensure that the major ideas, concepts and problems of the topic are generated by the context *naturally;* that it will

include those the student would learn piece-meal in a conventional textbook approach.

5. Secure the path from *romance to precision to generalization.* This is best accomplished by showing the student that

a. problem situations come out of the context and are intrinsically interesting,

b. that concepts are *diversely connected*, within the setting of the story *as well as* with present-day science and technology.

c. there is room for individual extension and generalization of ideas, problems and conclusions

6. The science story should be designed by the instructor, in cooperation with students, where he/she assumes the role of the *research-leader* and the student becomes part of an on-going research program.

My science education students and I have found that these guidelines are useful in designing any contextual setting, including science stories, especially in preparing early years materials. Later, in the senior years, we can relax the narrative requirements and concentrate on the theoretical and empirical aspects of the context.

The proper placing of science stories and LCP's.

How are we to place science stories and the LCP into existing curricula and teaching practices? After all, teachers are required to present the whole core curriculum content that has both definite theoretical and empirical requirements. In middle school science, and especially in senior high school physics, chemistry and biology, there is a standard theoretical as well as experimental content knowledge to be presented to the student. How can we ensure that this knowledge is taught more relevantly, in a more interesting and motivating manner, than using the conventional textbook-centered approach?

In the early and middle years I believe that the content can be placed in contextually motivating units that incorporate all of the topics, concepts and experiments the core curriculum requires. The design and the teaching of these contextual units, however, should be guided by the findings of science education researchers based on investigations into the development of students' scientific thinking skills (Driver, 1989, Kuhn et al, 1988). These findings suggest that "major development in scientific reasoning is the *differentiation of theory and evidence and the elevation of the process of theory/evidence interaction to the level of conscious control*" (italics mine, Kuhn et al, 1988).

I have developed a model to illuminate the interaction between theory and evidence that guide teachers in setting up contexts for the teaching of science (Stinner, 1992). To make the interaction more binding I introduced another dimension, namely the psychological (Stinner, 1992, also see Fig. 1). The model describes the requirements of the three planes of activity in science, the <u>logical</u>, the <u>evidential</u>, and the psychological On the logical plane of activity we encounter the finished products of a science, such as laws, principles, models, theories, and "facts". Textbooks present material chiefly on this plane. On the evidential plane of activity we encounter the experimental, intuitive, and experiential connections that support what we accumulated on the logical plane. The main question on this plane is : *How can we connect what we accumulated on this plane to the evidential plane?* The second question we should ask is: "*What are good reasons for believing that*...?" Here we are looking for evidence that "makes sense" to the student. The third question we should ask is: "What are the diverse connections of this concept?" Here we wish to show that the concept is valid when used in seemingly disparate areas in scientific inquiry. On the psychological plane we pay attention to the students' pre-scientific knowledge, and to their previous school science. Here we study the responses they have to some key questions we shall pose in testing their readiness to accommodate a concept. Textbooks generally are not directly concerned with the questions we must ask on this plane. This lack of concern suggests that most science teachers engaged in textbook-centered teaching pay little or no attention to how students' preconceptions interact with what is being taught.

In the senior years we can still place LCPs (and other contextual settings I will discuss below) centrally, providing we connect them to the contexts of inquiry in a given area of science. I have discussed the contexts of inquiry in some detail for physics elsewhere (Stinner, 19992). Following the requirements of the "contexts of scientific inquiry" teachers are able to state clearly what the presuppositions of a science, the major questions, and the central experiments are, and what new questions the science generates. According to my physics methods students, imbedding the LCPs in the contexts of inquiry in this fashion has the effect of liberating the teaching of physics from the grip of the textbook. Moreover, outlining the contexts of inquiry will place the study of science (physics) historically and will force the teacher as well as the student to engage in an inquiry process that is rooted in history and based on contemporary ideas of the philosophy of science. I have given a detailed outline of how we can imbed Newtonian mechanics into the contexts of inquiry, connecting to LCPs. (Stinner, 1989 b.).

For each major topic the experienced science (physics) teacher can outline the contexts of inquiry. In my methods classes my students and I have outlined this approach for other major topics as well, such as light and optics, electricity and magnetism, and modern physics. Moreover, we have begun to design LCPs for chemistry and biology and applied the contexts of inquiry approach in these areas.

Contextual teaching in science: from early years to senior years.

On the strength and success of incorporating contextual teaching into high school physics (LCPs) and of having designed science stories for middle years I would like to argue for a major change in the design of the science curriculum. This change would present a sequence of theoretical and empirical experiences by way of story-like approaches and contextual teaching from early years to senior years, involving contextual teaching, thematic teaching, and popular science literature teaching (see Fig. 3.).

The first is concerned with creating contexts that have a central unifying idea that attracts the students' imagination. These contexts then generate questions naturally that involve science as well as humanistic disciplines. The science story, contextual settings in early and middle years, and the large context problem are good examples of this approach.

The science story works well with younger students. Examples of science stories my students and I have developed are: *Archimedes' Adventures, Torricelli and the Weight of the Atmosphere*, *Galileo and the Inclined Plane,* and *One Day in the Life of Robert Hooke, FRS*. (Stinner A., Williams, H. 1993).

More specifically, for early years one would like to see a program of simple science stories that deals with the preconceptual world of the child. We want to recognize, respect and build on children's preconceptions, using motivating contexts that involve an exciting story-line and employing lots of hands-on activities. Ways to guide concept accommodation at this stage include discrepant events, sequencing of carefully designed activities, encouraging peer group discussions, using bridging analogies, providing an alternative theory to fit evidence, computer-based programs, and the designing of multi-media programs (Driver, 1989, Stinner, 1992).

Moreover, these stories should be connected to a program of activities suggested for an early introduction of physics by Osborne (Osborne, 1984). These activities would involve air-tables to study motion qualitatively, watching and discussing things falling in air and in vacuum, learning that words have different meaning in different context, discussing images from science fiction and, discussing the need for definitions in science, etc..

More general activities could also be included as suggested in Science works, An Ontario Science Centre Book of Experiments, such as "Ice fishing", "Inertia Trick", "Earth Speedometer", and "Solar Cooker". These activities, however, should be carefully chosen and properly sequenced, and often rewritten by science teachers. First, science teachers should create a context (using a story-line, however simple) that attracts the interest of the student. Secondly, science teachers should ensure that the activity and the sequencing is appropriate and fits into the curriculum. Thirdly, science teachers should create contexts (stories) from which the questions and problems arise naturally, unlike conventional science teaching where questions and problems are only connected to such topics and concepts as motion, substances, and classification. These early stories and contextual activities could be followed in the middle years by science stories based on history as well as by contexts based on students' experiences and on contemporary issues that students are interested in. Concurrently, and later in high school, we could introduce thematic teaching such as "A Brief History of Force" Stinner, 1993), and carefully selected stories in historical context. The criterion of selectivity here should be based on how well known the outcome of the story is. As I have already indicated telling the story of Galileo and the inclined plane often fails to make an impact if the results of the motion have already been learned from a textbook.

Teachers should capitalize on having students discuss science stories both formally and informally, thus offering different points of view. Indeed, children could eventually develop their own contexts (stories), and middle years students could be challenged to write for younger students. Solutions to problems which arise naturally from the contexts then can be presented by the students. The diversity offered by the different story-settings and contexts would then enrich the students' background knowledge as well as stir further interest.

Contextual settings, including science stories, of course, can also deal with the relationship between science and technology and society. Clearly, STS themes that are now very popular, can easily be accommodated by the contextual teaching I have discussed. Indeed, my students have developed LCPs based on such themes as *Nuclear Energy, Food Processing and Irradiation* and *Genetic Engineering*. STS issues will emphasize the added dimension of the relationship between science, technology and society. However, we must try to make context for STS teaching interesting for the student, roughly as suggested by the guidelines for writing LCP's and science stories.

The question of when it is appropriate to introduce STS themes is still open. It may not be appropriate, for example, to design a LCP involving nuclear energy with such objectives as teaching students to become "citizens that can participate more fully in the political and social choices facing society" (Brouwer, 1992) at the grade eight level. On the other hand, it is certainly commendable to try to turn students into "thinking, caring members of society, rather than on developing in them a fund of scientific knowledge divorced from its social context" (Brouwer, 1992).

The second is a story-like approach, aimed at senior years, that discusses science *thematically*, identifying general themes which transcend the boundaries of individual scientific disciplines and have interdisciplinary and humanistic connections. For example, the thematic couple of atomism and continuum "played an important role in shaping the conceptual structure of early twentieth-century biology and science" (Jordan, 1989). Other themata would be conservation, time, regularity, and evolution. These themes transcend individual disciplines and often link major activities in the various disciplines and touch on humanistic activities. Many science teachers, of course, already use, at least implicitly, such themes as the corpuscular nature of matter, the notion of conservation, and the wave-particle duality of matter.

The third approach to teaching senior science (and continued into undergraduate science) is attempting to use a wholly new kind of science writing that we can identify as *the third genre* of science writing (Eger, 1989). Well-known examples are: Stephen Hawking's A Brief History of Time, Steven Weinberg's The First Three Minutes, and E.O. Wilson's On Human Nature. Since about 1970 there have been more than hundred science publications (probably a conservative estimate) written for the lay public by top scientists in the world. These writings are often historical, almost always given in a narrative mode, connecting the scientist, as a person, to the prevailing scientific, cultural and humanistic ideas of the times. I have used these writings with science education students quite successfully. Students read one book critically and report to the class discussing the appropriateness of the content and presentation to teaching science in senior high school.

In the senior years we should introduce LCPs. Large context problems for chemistry and biology could also be developed and third genre literature could be introduced (for example, a discussion of fundamental forces in Stephen Hawking's *A Brief History of Time).* I have found that LCPs can be grouped in such a way that no matter which one the student picks from a given cluster, the content and processes covered will match those in the prescribed curriculum (Stinner, 1990).

Conclusions

I have tried to show how the idea of contextual teaching evolved from the modest hope of enriching textbook-centered physics teaching to an ambitious plan to teach physical science in general by way of story-like contexts from early years to senior high school.

From the beginning it was clear what the limitations of LCPs were (and indeed of all contextual teaching) when they were incorporated into existing science (physics) curricula. One limitation was that the LCPs were only peripherally connected to a textbook-centered curriculum. I argued that placing the LCPs centrally in the contexts of inquiry and using textbooks, but only as a reference, was one solution to this limitation. The other limitation was articulated as the content-context problem. I argued that a partial solution to this problem was based on early introduction of story-like contexts that pay attention to the three planes of activity, the *logical*, the *evidential,* and the *psychological.*

On the junior high school level in the physical sciences teachers find that students are frequently "turned off" science (Stinner, 1992). This is not surprising when one considers that they are routinely asked to perform tasks that are not connected, for the student, to an *evidential-experiential* base that "makes sense". The solving of problems based on *Ohm's law,* or the memorizing of *valences* of elements so that they can balance equations are good examples of such tasks. (At the high school level the problem becomes more acute because textbook-centered teaching, in the hands of the majority of teachers, leads to the emphasis of algorithm-recitation techniques.)

At the elementary school level contextual teaching has been traditional for a long time. Indeed, early-years specialists assure me that children demand interesting contexts in which to learn their science content, otherwise they simply refuse to listen. Would that middle school and senior high school students rebelled whenever the organized findings of a discipline are to be simply memorized!

Unfortunately, however, the vast majority of elementary school teachers are not science specialists. Many are afraid of science in general and of the physical sciences (especially physics) in particular. Consequently the delivery of "scientific facts", albeit in some contextual form, and their routine memorization by students is stressed.

Most elementary science teachers, therefore, would have little confidence in teaching physical science as envisaged in a program that calls for the design and execution of contextual teaching as outlined here. To do that we need physical science specialists to commit themselves to the teaching of physical science in the early years.

Ultimately one can envisage science being taught by way of contextual teaching from elementary grades right up to high school. In an ideal world, contextual teaching based on a "story line" approach could go on until specialization would seem to be inevitable. In such a world, science curricula would have to be changed, textbooks would have to be rewritten and their role reconsidered.

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