

**CURRICULUM AND INSTRUCTION DEPARTMENT**

**THE NATURE OF SCIENCE: WHAT TO TEACH AND HOW TO TEACH IT.  
BASIC PRINCIPLES FOR CURRICULUM DEVELOPMENT**

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## **The Nature of Science: What to teach and how to teach it**

### **Basic Principles for Curriculum Development**

#### **Introduction**

One of the principal goals of science education is that students develop an understanding of the nature of science (NOS), which is considered to be a key element in the achievement of scientific literacy. The capacity to learn, know and use science and technology to cope with the challenges of everyday life has become a commonly desired outcome of science education. Through the teaching of the NOS it is believed that our children will become better citizens, more conscious of their role within their community and environment. Ultimately, the goal is to safeguard our world for future generations. Due to the intimate relationship between NOS and scientific literacy, science educators from all around the world agree on the importance of developing and implementing accurate science curricula that boosts students' understanding of the NOS (Martin et al., 2000; W. F. McComas & Olson, 1998).

Despite the general agreement evidenced in the scholarly community in regard to the inclusion of NOS in the curricula, how to properly and accurately address this matter in classroom practice has been the subject of diverse and intense debates (Bell, Abd-El-Khalick, Lederman, McComas, & Matthews, 2001). The disputes revolve around different aspects of NOS teaching and learning and each brings various issues into play. For instance, the traditional universalistic perspective of science, where the

epistemological position of science is generally associated with Western Modern Science (WMS) has generated discontent among some science educators who believe the teaching of science should include a myriad of perspectives (Snively & Corsiglia, 2001). Another problem emerges when scholars discuss the use of constructivism as a teaching strategy for science education. When the different kinds of constructivism merge in the field of science education, the utility and validity of these ideas become unclear and ambiguous for science educators. Some scholars have advocated for emphasis on the individual creation of knowledge and construction of concepts, without disregarding the importance of the contemporary milieu for the development and validation of scientific ideas (Matthews, 1997). A final area of contention surrounds the exercise of giving NOS a definition in terms of its values and beliefs, which results in lists of tenets to be included in the science curricula. Some have argued that this will promote the inclusion of NOS in a trivial way as part of the content knowledge that students must learn through science instruction rather than something they would be learning along with their science education (Rudolph, 2000). Although these debates have been ongoing, the different suggestions provided by the scholars involved have failed to enlighten teachers and instructors in the development of curricula that effectively addresses the NOS. A more practical way of thinking about NOS in the curriculum would be welcomed by teachers and curriculum developers.

The spring semester of 2006 I worked as a project assistant for curriculum development at the Outreach department of the Synchrotron Radiation Center (SRC). In this position I had the opportunity to help in the development and implementation of the physics

curriculum “Let the Light Shine” (Appendix 1) a course that makes up part of the science section of the Pre-college Enrichment Opportunity Program for Learning Experience (PEOPLE) Program offered by the University of Wisconsin-Madison. In this course, I experienced first hand the difficulties teachers and curriculum developers encounter in attempting to incorporate the NOS into the classroom instruction.

In the project that follows I provide a survey of the contemporary debates about the NOS and science education improvement referred to above. While debating the finer points of the philosophy and sociology of science is pertinent to academics, their arguments do little to help teachers in the classroom. After reviewing this literature I have developed a set of curriculum design principles that I call the Basic Principles for Curriculum Development (BPCD). These, I propose, should be taken into account when developing science curricula that effectively addresses primary NOS principles. Given the general consensus about the importance of helping students in the development of an adequate understanding of the NOS, it becomes important to identify strategies that aid teachers in moving from the broad and abstract debates and consider more practical strategies for science education in the classroom environment. I want to emphasize that rather than pretending to use these curricular principles as the ultimate tool for science instruction or as a scaffold to develop assessments, the BPCD should be used in combination with other curriculum development ideas and pedagogical strategies. To illustrate this point, I provide a curriculum description and analysis of the workshop “Let the Light Shine” in light of the BPCD. Finally, I offer some practical applications for curriculum revitalization.

## The Debates

### Universalism vs. Multiculturalism

Traditionally science has been understood from a universal point of view, where the epistemological position of science is associated with Western Modern Science (WMS). Although this particular perspective serves well to explain the phenomena that surround us, it is driven by a homogenizing force that fails to acknowledge other ways to know about the world (Harding, 1991). Some scholars advocate that rather than presenting WMS as the only or main stream way to approach the world, other views like, Traditional Ecological Knowledge (TEK), ethnic sciences, and urban sciences, should be legitimized and given the same status in the science curricula (Barton, 1998; Snively & Corsiglia, 2001; Stanley & Brickhouse, 2001)

In his book *Science Teaching, The Role of History and Philosophy of Science*, Michael Matthews (1994) explains how Universalism presents science as a practice that cuts across all cultures, races, genders and religions. Although it is recognized that some aspects of culture influence science, Mathews considers that cultural influences do not determine the truth claims of science. By reading this book, Universalism appears to display science as an intellectual activity whose outcomes transcend human differences. In contrast, Matthews presents the Multiculturalist perspective of science which advocates for a equal consideration of ethnic sciences and WMS, for this scholar, the western view of science “is just one of a number of equally valid scientific views” (Matthews, 1998, p. 163)

Matthews makes clear that when scholars advocate for equal consideration of WMS and non-Western sciences in schools, this controversy becomes a matter of philosophical debate. Proponents of a multicultural approach to science education believe that not only ethnic sciences should be allocated in schools with the same status that WMS has reached, but it is also expected that students are presented with the different ideas of how each science is conceived. Moreover, some argue for a complete replacement of Western science when the students in the classroom come from minority and diverse backgrounds, which cannot be easily identified with WMS. “The truth status of Western science is challenged, and its monopoly on scientific understanding is questioned, if not denied” (Matthews, 1994, p. 181). WMS should be brought to an egalitarian position among other sciences.

The Universalism vs. Multiculturalism debate has also been explored by other science education researchers. For example, William W. Cobern and Cathleen C. Loving (2001) explain how universalistic perspectives, such as the one called the Standard Account, (see Cobern and Loving 2001, for further description), confer WMS with a biased epistemological authority to decide what is truth. The way WMS knowledge is taught in schools is traditionally considered to help the individual not only in the acquisition of a desired economic status, but it also provides power among the men and women that own it (Cobern & Loving, 2001).

Cobern and Loving explain this cultural hegemony of science in terms of “Scientism”, the view that there are no real limits to the competence of science; science is the boundary to what we humans can achieve or know about reality. “Scientism” leads us to the belief that “[t]here is nothing outside the domain of science, nor is there any area of human life to which science cannot successfully be applied” (Stenmark, 1997, p. 15). “Scientism” confers WMS with primacy over all other interpretations of life and fields of inquiry, generally dominating other domains of knowledge, i.e. Traditional Ecological Knowledge (TEK). TEK is considered the knowledge and insights acquired through copious observation of a particular place and/or specific species. “This may include knowledge passed down in an oral tradition, or shared among users of a resource. The holders of TEK need not be indigenous”. TEK, like scientific research, is scaffolded onto observation and experimentation, and it is utilized to comprehend and predict environmental circumstances upon which the subsistence or even survival of the individual depends (Huntington, 2000, p. 1270).

To combat “Scientism”, Cobern and Loving call for an epistemological pluralism that not only expands the definition of science, but also acknowledges that there is not a single origin of science, and that instead, there are many different legitimate sciences (Cobern & Loving, 2001; Harding, 1994; Kuhn, 1962). Learners should be able to approach and understand science from diverse points of view, such as religion, gender, and cultural differences with the purpose of recognizing the vast epistemological pluralism of our world (Cobern & Loving, 2001).

This debate is also deconstructed and reconceptualized by William B. Stanley and Nancy W. Brickhouse (2001). They “do not believe a Universalist view of science is either compatible with a multicultural approach or fully coherent as a foundation for science curriculum” (p.35). They oppose the universalistic position that views WMS as the “best” way of describing the natural world. Stanley and Brickhouse explain that the Universalist conception of science is scaffolded on assumptions, which express that reality is not associated with what we think or know about the world. This approach not only claims that reality is ordered having an invariant structure across time and places, but also states that “the structure of reality is knowable, at least in part, and WMS has provided the most effective and reliable way to discover knowledge about the natural world” (p.37). The later affirmation is perhaps what makes these scholars so skeptical about the universalistic view of science.

After showing their critiques against universalism, Stanley and Brickhouse, propose an alternative view of science focusing on a more local stance, rather than a global view. They argue for four particular positions that should be considered as leading towards a multicultural perspective of science. First, they state that it should be clear that human cognitive abilities determine the way we understand nature: “[a]s scientists fall under the influence of various theories and hypotheses, it becomes difficult not to see evidence that confirms our positions”(Stanley & Brickhouse, 2001, p. 40). In addition, they also stress the fact that we are part of a cultural and social reality that guides our observations of the natural world. In other words, what we know about the world is subjective because we are influenced by our cultural and social surroundings. Further, they say we should

describe science and reality as a flux, rather than something constant or invariant, because we are constantly re-conceptualizing it. Stanley and Brickhouse wrap up saying that, although there had been different attempts to provide evidence of science's unity across cultures, there is no point in such claim, since it is evident that science knowledge and content is shaped, not only by different cultures, but also by different forms and social organization of scientific research (Stanley & Brickhouse, 2001).

The aforementioned positions in regard to the Universalism vs. Multiculturalism debate are themselves ground for more critiques and further questioning. The case raised by Bradford F. Lewis and Glen S. Aikenhead (2001) points to other dilemmas that arose from the conflict between Universalism and Multiculturalism. These scholars mention the emphasis on Eurocentrism and the ambiguous advice provided by scholars who propose the inclusion of TEK into the science classroom with the same validity as WMS. Lewis and Aikenhead also think that, although these scholars are aiming to help teachers to address multicultural classrooms, their proposals fall short by not including plausible ways of addressing how this task should be done.

Finally, the aforementioned authors see the slow process of changing from Universalist perspectives to Multiculturalist ones as a "shifting paradigm" in school science. They suggest that the inclusion of history in the science curriculum will help to ease this process, stating also that we must be aware that these changes will not happen suddenly nor rapidly from one day to another (Lewis & Aikenhead, 2001).

Constructivism vs. Anti-constructivism

Another area of dispute among science education researchers has been the idea of constructivism and how it relates to science teaching and learning. For the last thirty years the field of education has been enormously influenced by constructivism. This doctrine presents students as active protagonists in the building and acquisition of their science knowledge. The educational process under a constructivist umbrella positions teachers as guides who facilitate students' re-construction of knowledge, while pupils build upon their own ideas through active participation to develop a deeper conceptual understanding of science.

Students are guided by teachers' scientific inquiry and are provided with opportunities to support and reflect on how the world around them works (Gil-Pérez et al., 2002; Kruckeberg, 2006). Constructivism is widely accepted and has great influence not only on educators and educational researchers but also among philosophers and sociologists of the twentieth and twenty-first centuries. For science education, constructivism represents a "paradigm change" as well (Kruckeberg, 2006; Matthews, 1997, 1998; Nola, 1997), from traditional classrooms where curricular activities rely heavily on textbooks in which students are viewed as "blank slates" and correct answers are sought to validate student learning, to a constructivist classroom where curricular activities rely on empirical data and hands on materials in which students are viewed as thinkers who have their own theories about the world that serve as a scaffold for subsequent lessons and conceptual development (Brooks & Brooks, 1999).

When educators undergo the task of developing curriculum in science, constructivism appeals to many. John Ogborn (1997) explains that this occurs because of the image learning takes under the lens of constructivist ideas. Here learning is viewed as an activity where students are active protagonists. In addition, it presents science as a non-objective and non-authoritarian practice, providing solution to the alienation of scientific epistemologies and facilitating the personal ownership of knowledge (Ogborn, 1997).

Despite the general acceptance of the idea, constructivism has been conceptualized from a myriad of perspectives which have allowed scholars to propose the existence of many variations of this doctrine. For example David R. Geelan (1997) classified six forms of constructivism as follows: (1) Personal constructivism, represented by scholars such as Kelly and Piaget, (2) Radical constructivism whose major representative is von Glasersfeld, (3) Social constructivism, as described by Solomon, (4) Social constructionism, explained by Gergen's philosophy, (5) Critical constructivism where Taylor is an influential proponent, and (6) Contextual constructivism which is explained by contemporary academics such as Cobern. Geelan pointed at a general trend in the historical development of constructivism from a personal objectivistic to a social relativistic process. His classification, rather than establishing a maturity or hierarchical arrangement, aims to differentiate from those who problematise the nature of scientific "truth" (i.e. Solomon, Tobin, Vygotsky) and those who explicitly recognize social learning but their influence has been on individual cognition (i.e. Cobern, Taylor, Gergen). After examining previous constructivist debates Geelan not only believes that there is a myriad of ideas that surround this practice, but also concludes that there are two

clear points that arise from previous discussions. First, he states, “[t]here is not, and should not be, ‘One True Way’ in constructivism”. He affirms that adopting different perspectives “is both more flexible and more powerful” (Geelan, 1997, p. 16). Secondly, the multiplicity in constructivism proponents has led to the use of different terms to describe similar things. These, Geelan believes, makes constructivism difficult to approach for the prospective learners of this practice (Geelan, 1997).

Another example, that provides a different classification for constructivism is found in Michael Matthews’s publication (1997). He has reduced the classification into three categories: (1) Educational, personal and social constructivism, (2) Philosophical constructivism, originated in Kuhn’s work, and (3) Sociological constructivism, which he explains in terms of the Sociology of Scientific Knowledge, making reference to Edinburgh ‘Strong Programme’ (Matthews, 1997).

Using Matthews work as a reference, Gürol Irzik (2000) also classifies the different forms of constructivism. He finds constructivism of the educational and social kind to be cognitive, epistemic, semantical and metaphysical. Irzik points at the flaws of these different views, stressing the ambiguity that the use of this vocabulary produces inevitably leading to the loss of the right or wrong idea in science education. In addition, he recognizes that constructivism is a reaction to the didactical, teacher-oriented “transmission model” of education (traditional education), and therefore he acknowledges that some constructivistic ideals have been beneficial to science education. For example, by accepting the fact that students come to class with their own “beliefs” which are

formed from their own experiences, teachers are able to develop a more student-centered curriculum, eliciting students ideas and using these to enhance their understanding of the NOS (Irzik, 2000).

Looking at the previous arguments, one may develop an understanding that most of the debate surrounding constructivism involves describing the essence of scientific work. The constructivist's epistemological commitments that define reality in a subjectivist, empiricist, and personalist way, and its ontological commitments seriously linked to realism and the "idealist idea that the world is created by and dependent upon human thought" (Matthews, 1994, p. 141) frame the constructivist science teaching under a series of problems. Irzik summarized these problems, concluding that the most eminent difficulties surge from the idea that knowledge is simply a human construct; he explains that this leads to the complication of finding correspondence between our representation of the world and the factual "truth". It seems that we cannot know anything about the world that surrounds us. Moreover, the radical position of seeing the teacher as a mere entity that solely aids in the construction of knowledge without telling students what concepts to construct or how to construct them generates a contradiction up to the point where some ask if there is a need for a teacher in the classroom. In addition, Irzik points at the difficulty of distinguishing between pseudo-science, discredited science and good science due to the lack of a serious epistemic or cognitive difference among the aforementioned (Irzik, 2000) . The belief that knowledge is not fixed by the world it seeks to describe has led some education researchers to condemn the use of this approach.

By narrowing down the polemics of psychological and social constructivism in the area of science education the ground becomes suitable for the formulation of several questions. Robert Nola (1997) believes that one should be asking particular questions when using constructivistic ideas in the development of curriculum, especially if one aims to generate valid scientific knowledge among students. Some of the questions that he proposes are: “Who does the constructing?” Is it pupils, teachers or both? Do they construct knowledge individually or collectively? “What is constructed?” Are they models, hypothesis, theories and/or knowledge? “What is the relation of constructing?” “How does one construct?” (p. 57). These questions pose some difficulties in the conception of constructivism as an educational practice and shows inconsistencies not only with constructivist’s philosophical statements but also with constructivist’s ontological and epistemological commitments (Nola, 1997).

The above difficulties and inconsistencies are responsible for the generation of continued controversies and confusion. Different scholars, aiming to clarify the muddy grounds of constructivism have been addressing the ambiguities through their writings. For instance, Ogborn states that confusion arises from the fact that “constructivist thinking ignores a kind of work of construction especially characteristic of science; the construction of theoretical objects of knowledge” (p. 126). He also states that “[t]he denial of ‘direct access’ to the physical world is either false, in that we do have causal access to it, an access which results in many of our beliefs about it being true beliefs” (Ogborn, 1997, p. 128). Additionally, Matthews explains that the relationship of constructivist pedagogy

and constructivist epistemology is unclear, and he advocates for using constructivist pedagogy, disregarding the confusing epistemological part on the understanding of human knowledge. Matthews' advice is to remove the epistemological commitments of constructivism explained above and to find a practical application of its pedagogy in the classroom (Matthews, 1997).

There are specific objections against the application to science of one form of constructivism, radical constructivism. In Nola's piece his objections are summarized in eight statements. He believes that radical constructivism in science education (1) "is partisan and not neutral about the nature of scientific theories and knowledge and science education", (2) "presents a distorted picture of the history and successes of science", (3) "is impotent to convey to anyone the body of well established theoretical truth that exists in science", (4) "depends on a discredited philosophy of science", (5) "interpretation of scientific theories does not ground, and is quite independent of, the constructive activities of students who learn scientific theories", (6) "with their talk of 'viability' and their relativist inclinations have lost the idea of a right and a wrong answer in science and science education". Nola also objects that (7) "[o]bjectivism adopts an authoritarian stance in science education and encourages passive learning while constructivism does the opposite", finally he says that (8) "[c]onstructivists have a distorted conception of knowledge which infects their view of learning"(Nola, 1997, pp. 77-80). Nola's suggestion of how to address these problematic issues to benefit science education is to renew the epistemology of science itself and its account of learning and teaching.

Although scholars stress the problems of constructivism, they recognize advantages of this doctrine. Matthews acknowledges some positive influences of the variations of constructivism, particularly for science education. He believes that constructivist statements benefit science education not only by acknowledging that students come to class with previously learned ideas and concepts, but also by stressing the importance of understanding the processes, boosting students' engagement, and raising educators' consciousness about the human dimensions of science (Matthews, 1997).

Accordingly, Ogborn emphasizes four important constructivistic ideas, which are worthwhile to keep in mind when thinking about science education. First, he says constructivism is good in the way that it acknowledges the importance of student's active participation and active learning. Additionally, constructivism stresses the importance of respect for the child and his/her ideas. Also, this doctrine supports the notion that science is built on ideas proposed by human beings. Finally, constructivism is beneficial in saying "that the design of teaching should give high priority to making sense to pupils, capitalizing and using what they know and addressing difficulties that may arise from how they imagine things to be" (Ogborn, 1997, p. 131).

Finally, a couple of important messages for teachers can be extracted from Geelan's work. One is that constructivism is self-created and we are involved in its ongoing development, therefore the importance of taking into account the different perspectives that give constructivism its pluralistic face. Hence, teachers should reflect on the different material brought by the multiple approaches to constructivism and select what best fits

their educational endeavor; “the right tool for the job, is the more powerful approach” (Geelan, 1997, p. 23)

*Lists vs. Actual practice*

Finally, one more debate in regard to the NOS has prevailed for the last decade among science education researchers. On the one hand, some scholars define the NOS in terms of its beliefs and values, and present these to science educators in the form of charts made of sentences, which are expected to be included in the science curricula. On the other hand, opponents to this checklist approach argue that these charts make the NOS become part of the content knowledge students must receive during science instruction. Rather, scholars advocate for these same concepts of the NOS to be available to pupils through student-centered curricular planning that include diverse activities and many opportunities for experimentation.

On behalf of making science intelligible to teachers and students, some scholars have devoted their practice to understand and define the NOS. In focusing on capturing its essence, lists of ideas have been created to describe NOS’ values and fundamental beliefs (Crowther, Lederman, & Lederman, 2005; Lederman, 1992; William F. McComas, Almazroa, Clough, & McComas, 1998). Table 1 provides a list example.

Table 1. McComas *et al.*, 1998.

### NATURE OF SCIENCE TENETS

- Scientific knowledge while durable, has a tentative character.
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism.
- There is no one way to do science (therefore, there is no universal step-by-step scientific method)
- Science is an attempt to explain natural phenomena
- Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence.
- People from all cultures contribute to science
- New knowledge must be reported clearly and openly
- Scientists require record keeping, peer review and replicability
- Observations are theory-laden
- Scientists are creative
- The history of science reveals both an evolutionary and revolutionary character
- Science is part of social and cultural traditions
- Science and technology impact each other
- Scientific ideas are affected by their social & historical milieu

These lists have been revisited repeatedly over the last decade; examinations of the NOS beliefs have led to the proliferation of tables which try to provide a simplified checklist of key ideas that define science. Some scholars not only believe that teachers should use

these lists while developing the science curriculum, but also think teachers should be explicit about the NOS' tenets when imparting classroom instruction. In addition, these lists should serve as a framework for assessing students' understanding of the NOS (Crowther et al., 2005; Lederman, 1999; Moss, Abrams, & Robb, 2001; Schwartz & Lederman, 2002). After reviewing several proposals on the NOS' beliefs, it is evident that some of the tenets have prevailed in the newer arrangements or have been grouped into single statements. Nonetheless, the essence of the NOS in these lists remains basically the same. For example, Lederman proposed that a student who holds an accurate NOS view should recognize that scientific knowledge is: (a) tentative (subject to change), (b) empirically based (based on and/or derived from observations of the natural world), (c) subjective (theory laden), (d) involved with human inference, imagination, and relativity (requires the invention of explanations), and (e) socially and culturally embedded (Lederman, 1999).

In 2002, Schwartz and Lederman acknowledged that there is not a single definition of the NOS that fully describes all scientific knowledge and enterprises. They also stated that there are some aspects relevant to NOS understanding that should be included in science curriculum and instruction. Again, central are the premises that scientific knowledge is: (a) tentative and can change due to revision, (b) scaffolded on empirical evidence, which is collected and interpreted based on current scientific perspectives as well as scientists' personal subjectivity, (c) the product of human imagination and creativity, (d) influenced by culture and society that play an important role in guiding scientific investigations, and

finally, (e) reflected in the ability to differentiate between observations, inferences, and scientific theories and laws (Schwartz & Lederman, 2002).

Most recently, Crowther *et al*, further reconstructed the NOS beliefs. Their list is compiled in Table 2.

Table 2. Crowther *et al.*, 2005

<b>NATURE OF SCIENCE TENETS</b>
<ul style="list-style-type: none"> <li>- Science is a way of knowing with values and beliefs.</li> <li>- Science teaching and learning is affected by its philosophical, historical, sociological and psychological context.</li> <li>- Science is a human endeavor performed by people of all ages, races, sexes and nationalities.</li> <li>- Science is based on evidence.</li> <li>- No single universal step-by-step scientific method captures the full complexity of doing science.</li> <li>- Creativity is crucial in the production of scientific knowledge.</li> <li>- New evidence and/or interpretation, replaces or supplements old ideas.</li> <li>- Basic scientific research is the mean to gain an understanding of the natural world for its own sake.</li> </ul>

The act of framing science under these tenets has generated some criticism. Brian J. Alters (1997) argued that whilst these lists give a clear definition of what the beliefs are, they do not address the specific issue of how one can get to handle and own such statements. He also speaks of the assessment tools developed to measure students' understanding of the NOS, believing that such evaluations only tell whether pupils see the world in a particular way. After acknowledging the multiple and diverse tenets that have been distributed among the science education research community, Alters raises a very important question: "Who decides for science education organizations and researchers the primarily philosophical based questions of what are the tenets of the NOS?" (Alters, 1997, p. 42). He believes that philosophers of science should be brought into the picture not only to examine the different proposals about the NOS beliefs, but also to provide some guidance in establishing more precise criteria for the NOS. After conducting his study, Alters concludes that there is not agreement on the NOS beliefs and the question remains: "Whose Nature of Science?"

In line with this critique, John Rudolph (2000) points at the scant success the integration of lists into the curriculum has had for students to achieve a better understanding of the NOS. Rudolph believes that the utilization of lists is problematic, because when teachers change their practices from traditional universalistic views towards multicultural approaches to science education, the lists fall short in explaining the real substance of the NOS. The lists which "define" the NOS are either too broad or too specific and put teachers in difficult positions. On one hand, broad lists that describe the NOS are vague and allow for pseudo-sciences to be portrayed as valid forms of science. And on the other

hand, a very narrow and specific list becomes too strict in the definition of what NOS is, leaving out of the panorama practices that are considered scientific. Rudolph argues for a more natural integration of NOS into the traditional school science curriculum, where students are provided with opportunities to understand and practice science themselves. While pointing at the difficulty of presenting students with the different competing views of the NOS, Rudolph proposes that local discussion and negotiation should take place in the process of developing curricula that meets the specific needs of every classroom, and he gives two suggestions for the elaboration of the curricular plan. First, he advocates for the integration of school subjects around historical contexts that give students a better chance to make sciences intelligible. Then, Rudolph proposes to build the curriculum “upon the modeling activities of the scientific research community” (p. 410) to produce coherent pictures of the world as a whole, bringing it closer to the every day workings of science, and in this way enabling students to understand science for what it includes rather than for what it is (Rudolph, 2000).

### **Implications for Science Education – What do the debates tell us?**

#### *The Basic Principles for Curriculum Development*

After reviewing the controversies that surround the teaching of the NOS, it is clear that a common and central intent of all the debates is to improve the teaching of science. NOS is considered to be a key element in the achievement of scientific literacy (Moss et al., 2001). Scientific literacy is defined as the capacity to learn, know, and use science and technology to cope with the challenges of everyday life (Miller, 1998; Roth & Lee,

2002). Because of the close association of NOS and scientific literacy, improving students understanding of the NOS and increase scientific literacy among students have become major goals for science education. The idea that science is highly valued in many societies has proven to be powerful for at least the past eighty years. Science is not only believed to better citizens' lives, but also the understanding of science has been shown to be correlated with economic growth and personal satisfaction (Gruenberg, 1935). Science is "an important force for human improvement and it offers a uniquely privileged view of the everyday world" (A. Irwin & Wynne, 1996, p. 6). It has become an essential part of our cultural understanding and it is important in the construction of a modern democracy. An improved understanding of the NOS is of great personal and national value (A. Irwin & Wynne, 1996).

For these reasons, a call for the improvement of students' understanding of the NOS has been placed by "[n]early every key science education policy document in the USA" (Rudolph, 2000, p. 403). We need students not only to understand science, but also to become engaged with science in different contexts. Science educators from around the world agree with the importance of developing and implementing accurate science curricula that help students become scientifically literate, enabling them to utilize science and effectively make sense of the world that surrounds them. Ultimately, it is intended that students develop the ability to better cope with the every day challenges of the world through achieving a proper scientific literacy (Martin et al., 2000; W. F. McComas & Olson, 1998; Roth & Lee, 2002).

In the paper “*In Defense of Modest Goals When Teaching about the Nature of Science*” Michael R. Matthews (1998) brings up an important point that deserves careful consideration for the development of this work. Although it is clear that a proper understanding of the NOS is a key element for science education and is central to the different approaches to teach science, e.g. feminism, multiculturalism and constructivism, science education researchers and science educators should not pretend that students grasp everything that the aforementioned debates bring to discussion in regards to the NOS (Matthews, 1998). Forming a complete and accurate conception of the NOS seems to be a very puzzling enterprise not only for our students, but also for science teachers. The disputes generated around the teaching of science in schools go beyond the classroom capacity, raising the question: What is worth including when teaching for a better understanding of the NOS?

Matthews argues that teachers should seek for students to develop a more complex, rather than a total or complete, understanding of the NOS. Time should be allotted for students to philosophize on questions like “What do you mean by...?” and “How do you know...?” (p.169). In addition, Matthews also emphasizes the importance of presenting students with controversial issues. These suggestions aim to promote critical and reflective thinking among pupils (Matthews, 1998).

While taking into consideration the presented debates about the NOS and the substantial agreement in regard to the importance of including NOS principles in science education (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Smith, Lederman, Bell, McComas,

& Clough, 1997), for the purpose of this project, I will use Matthews' recommendations and propose modes goals for the inclusion of NOS throughout the science curricula. Like Matthews, I believe teachers should aim to better students' conceptions of the NOS little by little, "[t]hey need to crawl before they can walk, and walk before they can run" (Matthews, 1998, p. 169). Additionally, I argue it is important to extract from these complex debates the basic ideas that will aid teachers and students in achieving a better, rather than a total, understanding of the NOS. The ideas suggested in Table 3 are the Basic Principles for Curriculum Development (BPCD) that I recommend teachers take into account during the development of curriculum that effectively addresses improving students' understanding of the NOS. Each of these design principles will be expanded upon in the next section.

**Table 3.** Basic Principles for Curriculum Development (BPCD) that effectively address the NOS.

<b>Basic Principles for Curriculum Development</b>
<ul style="list-style-type: none"> <li>- Science is <i>a way of knowing</i> about the world</li> <li>- There is <i>not one way to elaborate</i> science</li> <li>- Scientific knowledge <i>is tentative</i></li> <li>- Science is a human endeavor, it is <i>socially and collaboratively constructed</i></li> <li>- <i>Empirical evidence</i> is the foundation for scientific knowledge</li> </ul>

Of course there are additional ideas that may be considered when teaching about the NOS, specifically in light of the concepts discussed at the beginning of this paper. Notwithstanding, the principles identified in Table 3 are consistent with the different approaches to the NOS discussed before, and also represent a modest goal for the improvement of NOS teaching. The BPCD should be considered the first steps towards bettering science curricula and to competently address the basic aspects of the NOS in the classroom.

In providing this starting point, it is important to mention that there is no need to attempt to include all principles every time science instruction takes place. Throughout the development of different lessons, teachers should include little by little these principles. This serves to avoid overwhelming students and instructors. It is also important to mention that while some principles are easy to accommodate, others will be challenging and require a greater and/or extended effort to meet the expectations of science education.

At this point, the reader might be thinking about the applicability and meaning of the aforementioned curriculum design principles in relation not only to science curriculum development, but also to science instruction. In the following section, some explanation is provided for the inclusion of these aspects of the NOS.

*The Meaning of the Basic Principles for Curriculum Development*

By understanding that Science is *a way of knowing* about the world, pupils should be able to comprehend that, although Western Modern Science (WMS) has long been considered the science for excellence, and its views serve well the purpose of making scientific phenomena intelligible by giving plausible answers to most of the questions that arise in our daily relationship with the world, this particular perspective is not the only way to understand the universe. Whenever possible, it is important to present students with other perspectives about the world (i.e. cultural, religious, ethnic and/or Traditional Ecological Knowledge (TEK)) when teaching about science. This approach should be used not to place these particular views of the world in controversy with the WMS, but to acknowledge that there are different and legitimate ways parallel to WMS that explain the phenomena of the universe (Cobern & Loving, 2001).

Also, it is fundamental to elicit students' ideas when introducing new content knowledge. Looking at the previous debates, one of the important legacies from constructivism is the view of students as thinkers who have their own ideas. The conceptions students bring to class need to be acknowledged and brought into discussion and considered during instruction, these should serve as a scaffold for the development of student-centered curricula, that provide students' construction of knowledge an ownership account (Irzik, 2000). Along these lines, by considering students' preconceptions of the world instructors can make evident for their pupils that our understandings of the world are influenced by different factors like our cultural backgrounds.

In addition, teachers can use other approaches to knowledge building that provide alternative or complementary explanations to the topic being studied. For example, if the class is focused on ecology, the inclusion of case studies where TEK has been used to complement scientific investigations would be appropriate and valuable, i.e. research on Pacific herrings after the *Exxon Valdez oil spill* in Alaska (Huntington, 2000).

Also, students should appreciate that there is *not one way to elaborate* science, meaning that pupils need to learn about the different methods in which science may be conducted. This should eliminate the widely held misconception that science is done by following a single, universal scientific method. Our students are part of a new technological era that invites exploration, rather than the following of a specific path from A to B (Kapitzke, 2003). Instead of introducing “The Scientific Method” as a series of “logically ordered” steps that should be done while developing scientific investigation, teachers should plan on using scientific inquiry (constructivist pedagogy) and present students with the different aspects of investigation (i.e. observation, hypothesis formulation, experimentation, etc), as pieces of a larger puzzle. Guided by questions, and utilizing the different features of science exploration, students should be able to propose plausible ways in which they could approach the scientific enterprise and develop diverse accurate methodologies to do so. Furthermore, the comparison and study of different methodologies used in scientific investigations would serve the purpose of helping students to become aware of the multiple ways in which science can be done.

By understanding that scientific knowledge *is tentative*, students learn that what is considered to be “truth” at a specific period in the development of science might be different from what is valid or accepted at another time. Also, pupils should become aware that facts and theories are a matter of scientists’ subjective interpretations and subject to revision and reevaluation (i.e. peer review); what is accepted now might also differ from what would be considered to be right tomorrow. To address this BPCD, teachers can use history of science and scientific models to contrast and compare scientific knowledge through time (Rudolph, 2000). Teachers can focus on the different results scientists have obtained in regards to the same issue or phenomena at different periods of time. For example, in studying the atomic theory, teachers can have students compare the achievements and different models of respected scientists like Niels Bohr, Ernest Rutherford, and James Chadwick (French & Taylor, 1979). Pupils can study and analyze scientists’ work, and understand that new ideas surged from the need to find better explanations about the phenomena of the world.

In having students appreciate that science is a human endeavor, and that it is *socially* and *collaboratively constructed*, pupils should comprehend that science is not a solitary pursuit and that group work is important for the advancements of the scientific enterprise. Also, they should acknowledge that these processes require time and human input. By including history of science in the development of the curriculum, teachers can integrate these ideas. For example, allowing students to get to know about the mentor/work relationship that Rutherford and Chadwick had in studying the emission of gamma rays from radioactive materials (Nollet & Pöschl, 2006), pupils can see that scientists work

together towards the development of scientific knowledge. To model this practice teachers should teach and encourage students to work in cooperative learning groups, by assigning roles to each member of the group and rotating them during the scientific investigations. Teachers should not expect that these group activities are void of the problems of socialization. Some advantage can be taken from the struggles students may face when working in groups; this could serve for pupils to undergo some of the challenges scientists face in the development of their work.

Finally, and perhaps one of the most important principles to be addressed in science instruction, is to make students aware of the fact that *empirical evidence* is the foundation for scientific knowledge. Pupils should realize that conclusions are not made arbitrarily, careful experimentation, extensive data gathering, and thoughtful analysis are necessary for drawing conclusions in scientific research. The science curriculum should provide several and diverse opportunities for students to experiment. They should have the chance to state questions about their surroundings and formulate hypotheses that can be tested through the implementation of valid experiments. Finally, based on the gathered empirical evidence students should be able to make science more intelligible to them by analyzing and drawing conclusions from their experiences. The inclusion of activities that capture information from the environment is fundamental, not only for improving students' understanding of the NOS, but also to interest students in the practices of science.

In conclusion, along the lines of constructivist pedagogy, it is important to note that each of the aforementioned principles should be addressed after taking into account students' previous ideas. Teachers should be aware whether students' ideas about science partially or completely coincide with the facts of science, or if they are scaffolded on mythological and/or fantastical conceptions of the world. Also, the science curriculum should provide classroom activities that focus on inquiry learning methods. When thinking about science instruction teachers should seek to make their classes student-centered, have pupils lead in the processes of discovering and learning, and ultimately help them to make sense of science (Ogborn, 1997).

After having developed the BPCD (Table 3) and explained the rationale for considering these principles for the development of curricula that effectively addresses the NOS, it becomes necessary to present a practical application. The Pre-college Enrichment Opportunity Program for Learning Experience (PEOPLE program) of the University of Wisconsin-Madison provides an excellent opportunity to study science curricula that was developed without specific NOS guidelines. This is one of many places where these principles for science curricular development might be utilized.

### **The PEOPLE program**

*Diversity of viewpoints, diversity of backgrounds, including gender and ethnic differences, as well as variety within academic specialties, are all vital components of the intellectual life of this great university. This not only contributes to the academic vitality of the campus, but also makes us more competitive among our peer institutions. While parts of the campus have made significant gains, our overall progress in reaching greater gender and ethnic diversity has been too modest. If we are to be successful in the future, we must tap the rich potential of all our citizens by incorporating them into our faculty, staff, and student body.*

*David Ward, Chancellor, in A Vision for the Future, 1995*

In an effort to counter the low number of minority students and faculty that attend the University of Wisconsin-Madison Chancellor David Ward instituted the diversity program, University of Wisconsin–Madison Plan 2008. This program calls for institutional improvements designed “to prepare students from all ethnic backgrounds to live and work in a racially and culturally diverse world” (p.3). Ward seeks to improve leadership and responsibility, recruitment and retention of undergraduate and graduate students, as well as faculty and staff that belong to minority groups. He also emphasizes the importance of finding financial aid through community and alumni cooperation and involvement. Within this plan, particular focus is given to the necessity of increasing the number of minority students on campus (University of Wisconsin, 1999).

Ward’s vision prompted the development of the PEOPLE program, created and designed to attract minority students with strong academic potential who are U.S. citizens or permanent residents of the United States. This program has been specifically focused on recruiting students that are African American, American Indian, Asian American (with an emphasis on Southeast Asian Americans), Chicano/a, Puerto Rican, Latino/a, and first-generation college bound students. The PEOPLE program also aspires to encourage students to pursue college careers in the Science, Technology, Engineering, or Mathematics (STEM) areas. By inviting minority students from Milwaukee, Racine, Madison area, and some of Wisconsin’s tribal communities to attend the PEOPLE program. The PEOPLE program not only aims to encourage high school minority students to finish school academically prepared for college, but also wants them to attend

UW-Madison increasing enrollment and graduation rates of students from diverse backgrounds (University of Wisconsin, 2006). UW-Madison hopes that, upon finishing high school, students will opt to attend college and choose this institution to pursue their professional careers. UW-Madison expects to step forward in reaching the goals of the University of Wisconsin Madison plan 2008.

The PEOPLE program serves more than 1,100 minority and low-income students attending partner Wisconsin public schools each year, offering classes in the areas of reading, writing, mathematics, English, science, social studies and foreign languages (University of Wisconsin, 2006). Also, this program offers enrichment opportunities that last one, three, or seven weeks during the summer. The one-week workshops are imparted for middle school students, while the three- and seven-week workshops are designed for high school students. During their first two years of attendance, 9<sup>th</sup> and 10<sup>th</sup> grade students receive instruction in math, writing, arts, study skills and three different science areas, biology, health sciences, and physical sciences and engineering. By their third year, 11<sup>th</sup> graders specialize in one area for the duration of the three-week workshop, and finally during their 4<sup>th</sup> year, 12<sup>th</sup> graders attend a seven-week internship in partnership with UW-Madison academic staff. During the time students stay in UW-Madison, they are busy attending several classes and activities every day. Students and instructors meet daily to discuss the implementation and advancement of workshops and projects.

Instructors of the PEOPLE program are selected from varied applicants; they are mainly graduate or upper-level undergraduate students from UW-Madison who are responsible for the development of the curriculum of these courses. Also, university scientists and academic staff contribute to the development of the PEOPLE program activities and workshops. Before the courses start, principal instructors are partnered with teachers from Milwaukee and Madison area. By the beginning of the program, each section has at least three instructors from diverse backgrounds such as chemistry, physics, ornithology, ecology, engineering, mathematics, education and medicine among others.

Every year the PEOPLE program offers nine to ten science sections from which students can choose according to their interests and preferences. During summer 2005, the sections offered were Ecotoxicology, Organismal Genetics, Human Psychology and Behavior, Physiological/Behavioral Attributes of Species, Genetics of Diseases, Chemistry, Mechanical Engineering, Civil & Environmental Engineering, and Physics of Light. Most of the classes remained the same for the following year. The subjects offered depend upon the science coordinator for the PEOPLE program, who depends on input from academic staff of the STEM areas and the outreach departments of the university's research facilities. Last summer (2006) the PEOPLE program offered science sections that focused on themes that included: Neurosciences, Earth Sciences, Ecology & Ecosystems, Birds, Behavior & Conservation, Chemistry, Mechanical Engineering, Civil & Environmental Engineering, Behavioral Sciences, and Physics of Light. This year (2007) the program is expecting to offer workshops in the areas of Cell & Molecular Biology, Organismal Physiology and Animal Behavior, Ecology & Environmental

Sciences, Chemistry, Nanotechnology, Physics, Biomedical Engineering, Mechanical Engineering, Civil and Environmental Engineering, Health Sciences, and Earth Sciences.

It is important to mention that students that attend the PEOPLE program do not receive a final grade. Summative and formative assessments of content knowledge are rarely implemented. Nevertheless, students are expected to maintain a minimal GPA of 3.0 in order to be eligible for the program and individual academic progress is followed in high school by tracking students' grade reports every quarter upon their admission to college.

The curricula developed to cover the different themes emphasize hands-on and inquiry activities. The sections explicitly aim to encourage excitement about science among students and help them create useful associations to address the challenges of everyday life. Among other things, students have the opportunity to explore career possibilities and are introduced to the breadth of scientific research at UW-Madison. Overall, the PEOPLE program provides rich opportunities for students to learn about the processes of science (University of Wisconsin, 2007). In addition, the coordinator of these science sections, outreach program manager Robert Bohanan, considers the improvement of the NOS to be an important outcome of the program. In collaboration with undergraduate and graduate students, Bohanan developed a survey that attempted to measure students' understanding of the NOS before and after they participated in the PEOPLE program's instruction. Although the details of the survey are not relevant for this discussion, it clearly indicates that NOS is a main focus of the program and desired outcome. Since a good understanding of the NOS is considered to be a key element in the achievement of

scientific literacy (Moss et al., 2001), it becomes important to know to what extent the PEOPLE program's courses are developed and designed to foster a better understanding of the NOS among the students.

The following section of this document is an analysis of the physics section offered last summer (2006) by the PEOPLE program. The ultimate intention is to deconstruct the curriculum "Let the Light Shine" in order to identify what evidence of NOS inclusion and instruction can be found. Finally, based on the BPCD (Table 3), some ideas are offered for curriculum improvement and revitalization.

### **The Curriculum: Let the Light Shine**

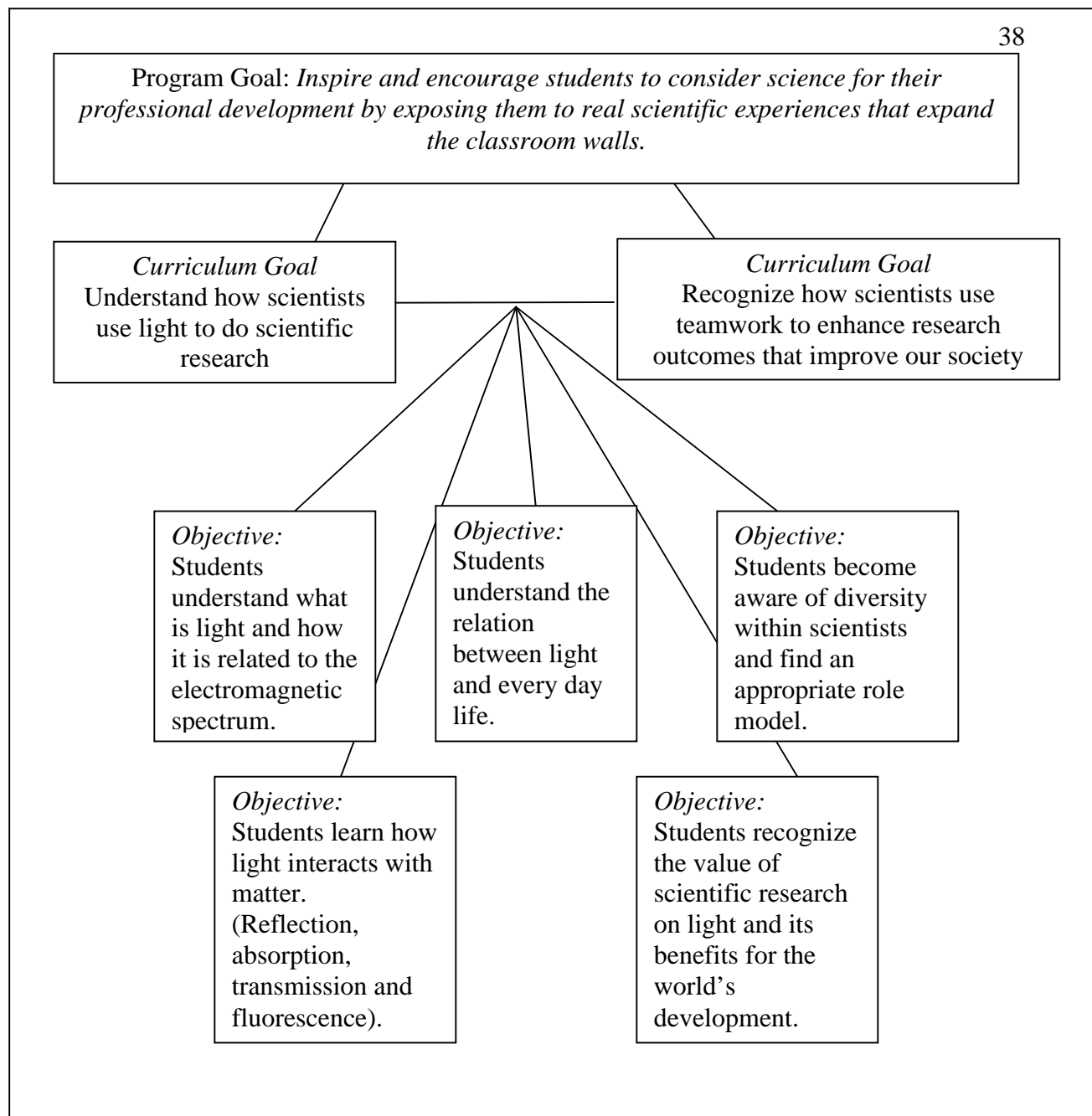
The goal of all curriculum design should be not only to keep the focus on students' interests, but also to have a holistic understanding of the students' needs and how those needs can be fulfilled under specific contexts (Pinar, Reynolds, Slattery, & Taubman, 1996; Tyler, 1949). As part of the PEOPLE program, the Synchrotron Radiation Center (SRC) offers a science enrichment class in the area of physics. Two previous teachers, Christopher Moore (physicist and outreach specialist for the SRC) and Dan Wallace (physicist, associate instrumentalist for the SRC, and former high school physics teacher), and I (biologist, project assistant for the SRC at the time, and graduate student in Curriculum and Instruction with an emphasis in Science Education) developed the physics curriculum, "Let the Light Shine" (Appendix 1). The intention was to promote personal, meaningful, and enjoyable activities for students to engage with physical

sciences, not only for the three weeks the PEOPLE program instruction lasts, but also, and more fundamentally, with the hope that students choose to include physics classes in their future high school and college studies (Figure 1).

At the time we developed this curriculum, the NOS was not given any particular consideration and the BPCD were certainly not used. When a science curriculum is developed in this way, the desired outcomes might not be achieved. What follows is a description of the curriculum “Let the Light Shine” followed by an analysis of the ideas related to NOS that naturally emerged, remained hidden, or were not addressed in the course. Finally, this is followed by suggestions for how the NOS could be more fully integrated into the curriculum based on the BPCD.

*Curriculum Description:*

As originally developed, the curriculum “Let the Light Shine” exhibits aspects of subject-centered curriculum design, an arrangement that implies the curriculum is built around one or more subjects with lectures as the main teaching style. Nevertheless, by using light as the central topic for the development of instruction in the areas of mathematics, chemistry, physics, and reading and communicative skills, the curriculum could be considered to be core-designed, where some content is required for all students to know, and the teachers or instructors articulate two or more subjects or disciplines around this content (Henson, 2001).



**Figure 1.** Program goals, course fundamental goals and course objectives for the curriculum “Let the Light Shine”.

The core of this physics curriculum is light. It is intended that all students learn throughout the development of the course aspects about history of light research, the

electromagnetic spectrum and its different kinds of light, the light's properties, the wave's characteristics and the functioning and use of the spectrometer.

This workshop began with the administration of a pre-assessment to students. It was intended to determine what conceptions they brought to the class about atomic structure, light properties, the use of computer spread sheets, scientific notation, and electromagnetic waves present in our daily life. This pre-assessment mainly served to place students into cooperative learning groups (Appendix 2).

Teachers lectured or discussed with students different kinds of issues related to light. For instance, it was explained to students that the term "electromagnetic" describes the light type of radiation because light results from interacting electric and magnetic fields. Also, after introducing students to the light spectra and the spectrometer, discussion about the kinds of radiation and their differences took place. Teachers told students that although radiations differ by energy, frequency, and wavelength, they can all be described by the same mathematical relationships:  $\text{Energy} = \text{constant} / \text{wavelength}$ . Other ideas brought into class discussion included how light is useful in our daily life and the implications light has with our health.

Almost every day, time was devoted to review particular content that was thought to be crucial for students to develop an appropriate understanding of the light concepts. A lot of emphasis was placed on the scientific method as the primary way for doing scientific research. Also, math reviews were frequent to clarify the scale and scientific notation

concept and to aid the students' learning about wave's characteristics and properties of light.

Different activities were implemented to facilitate the introduction of the content knowledge. For example, a prism was used to diffract light into the wall to show the spectrum of light. With the aid of teachers, students cooperated in the establishment of the spectrum range, placing marks on the wall and finding the limits for visible light. This activity also served to introduce the invisible light of the electromagnetic spectrum and also prompted discussions about the different effects they might have on human health. Group discussion took place during these exercises. Students answered questions like: Are the visible colors the limits of light? What other kinds of light are not visible? How are different kinds of radiation dissimilar? Additionally, diffractive and refractive properties of light were studied; when using mirrors, students mixed the colors spread by the prism together to obtain white light again.

When instructing students about the wave's characteristics, kids were brought to the front and modeled waves using a rope and their bodies. Teachers introduced longitudinal and transverse waves, and it was explained that waves need a disturbance to occur and a medium for propagation. This activity was reinforced by using an oscilloscope to show sound waves and allowing students to play with this apparatus and make music at the end.

In order to introduce students to the spectrometer, a demonstration with a glowing pickle was performed. By using two nails, a pickle, and a power source to apply voltage to the pickle, a yellow light was produced and measured with the spectrometer. Teachers discussed with students the utility of such an instrument for the scientific enterprise, and to get students more involved, they were given the materials to build a spectrometer on their own. An opportunity for pupils to gather data was set up in the classroom by using lamps of different elements like helium, krypton, and sodium, among others. Using handouts, students recorded their observations and shared their findings within and between their cooperative learning groups. Additional opportunities to work with the spectrometer were provided, a demonstration with burners and different substances was performed where teachers made the flame glow with different colors and students observed the light emissions through their spectrometer. Also, two experiments were set up for students to gather data, analyze and formulate conclusions based on the content knowledge they had acquired.

For students to make real life connections, instruction and two field trips were scheduled for the second and third week of classes. One of the exercises developed for students to understand the relation between light and everyday life (Figure 1) was a reading activity about light and health. For this, students' ideas about nocive effects of light were elicited, and then four different readings were distributed among the different cooperative learning groups. By the end, students shared their information about light therapy, skin cancer, vitamin D fixation and bone growth, and UVA & UVB light. The class was wrapped up doing a sunscreen activity with UVA sensitive beads and sunscreen. The first field trip to

the Synchrotron Radiation Center (SRC) was intended to introduce pupils to the research facility. Students had the chance to witness how light is used at the SRC in scientific investigations, interact with technicians and scientists, and receive instruction about the SRC monochromator machine. For the second field trip, children had lunch with some of the scientists who were doing scientific research at the SRC beam lines during the summer of 2006. After lunch, the visitors were divided into their cooperative learning groups, and each team worked with scientists and mentored students on one specific project and students helped in that day's data collection.

As a way to enhance the cooperative learning outcome, students were provided with cameras and notebooks during the first week of instruction. In addition to having kids take notes that help in their learning process, it was also intended that they documented their experience, sharing their different perspectives within their groups and with their classmates by creating a poster. Teachers gave students guidelines for this activity and devoted enough time for students to design, arrange and present their posters.

A particular activity took place when Eric Wilcox, an African-American astronomer who is the chair of the astronomy department, was invited to visit the classroom. Wilcox gave an experiential speech to the students, opening the conversation to discussing not only his professional development and achievements, but to also talking about the particular struggles he had to confront in his academic development as a member of a minority race group in the USA. By bringing this person into the classroom, it was intended that

students had the chance to identify with him and become aware of the cultural and racial diversity within the scientific community (Fig 1).

At the end of this workshop, a post-assessment was administered to students and evaluated immediately by the instructors in order to give pupils some feedback on their improvement in the subject of light.

*Curriculum Analysis in Light of BPCD:*

For the analysis of this curriculum (Appendix 1) the Basic Principles for Curriculum Design (BPCD) (Table 3), were used for coding the activities that took place each day of the workshop. The codes used for each principle correspond as follows:

<b>Basic Principles for Curriculum Development</b>	<b>Code</b>
Science is <i>a way of knowing</i> about the world	Swk
There is <i>not one way to elaborate</i> science	Se
Scientific knowledge is <i>tentative</i>	Kt
Science is a human endeavor, it is <i>socially and collaboratively constructed</i>	Scs
<i>Empirical evidence</i> is the foundation for scientific knowledge	Ee

A detailed evaluation of the activities was performed in order to identify what BPCD were addressed everyday and overall by the implementation of this curricular plan (Appendix 1).

By reading the curriculum description and going through the coding analysis, it is evident that the way the curriculum was developed and implemented strongly addresses two of the proposed BPCD elements. In the elaboration of the activities for the class instruction, the basic principle of science being *socially* and *collaboratively* constructed was constantly addressed, (days 1, 2, 9, 11, 12, and 14). By placing students in cooperative learning groups, promoting discussion among and within the groups, using teamwork to develop scientific research, and having students present their work to their peers, teachers are helping students to realize the importance of teamwork in the development of scientific knowledge.

Also, the notion that *empirical evidence* is the foundation of scientific knowledge was strongly stressed. By implementing hands-on activities (days 4, 5, 6, 12, 13 and 14), demonstrations (days 1, 2, 4, 5, 8 and 13), and experiments (days 9, 10 and 11), teachers can expect that students become aware of the importance of manipulation, observation, and testing as principal components of scientific research, and appreciate the significance of these as a scaffold for the building of scientific knowledge.

On the other hand, the activities performed throughout the workshop barely confronted the idea that scientific knowledge is *tentative*. For example, during Day 2, some discussion about history of light research takes place, but no attempt is made to focus on the changes that have occurred in this area. Also, the atomic structure was introduced during Day 6, and little time and emphasis was devoted to using it as an example of how

scientific knowledge is subject to revision, and that it changes according to scientific research.

Unfortunately, by planning curriculum without critically thinking about the NOS, not only do teachers miss the opportunity to accurately address some basic principles, but they also can fall into misleading practices. The idea that there is *no one way to elaborate* science is inaccurately addressed by the “Let the Light Shine” curriculum. There appears to be a fixation with “The Scientific Method”; this is presented by instructors, not only as an organized step-by-step methodology, but also as the true and only method of scientific practice. This rigid view of the scientific practice appears to be the backbone that structures the development of the course (Figure 2), and it is explicitly emphasized in the lessons of days 2, 4, 11 and 13. The inclusion of alternative instructional approaches that show students other ways of doing science would provide clarification over this widely held misconception about the practice of science.

Finally, absent from the activities implemented in this physics workshop is the idea that science is *a way of knowing* about the world. No alternative views are presented to students and WMS is shown as the only way to know about the world.

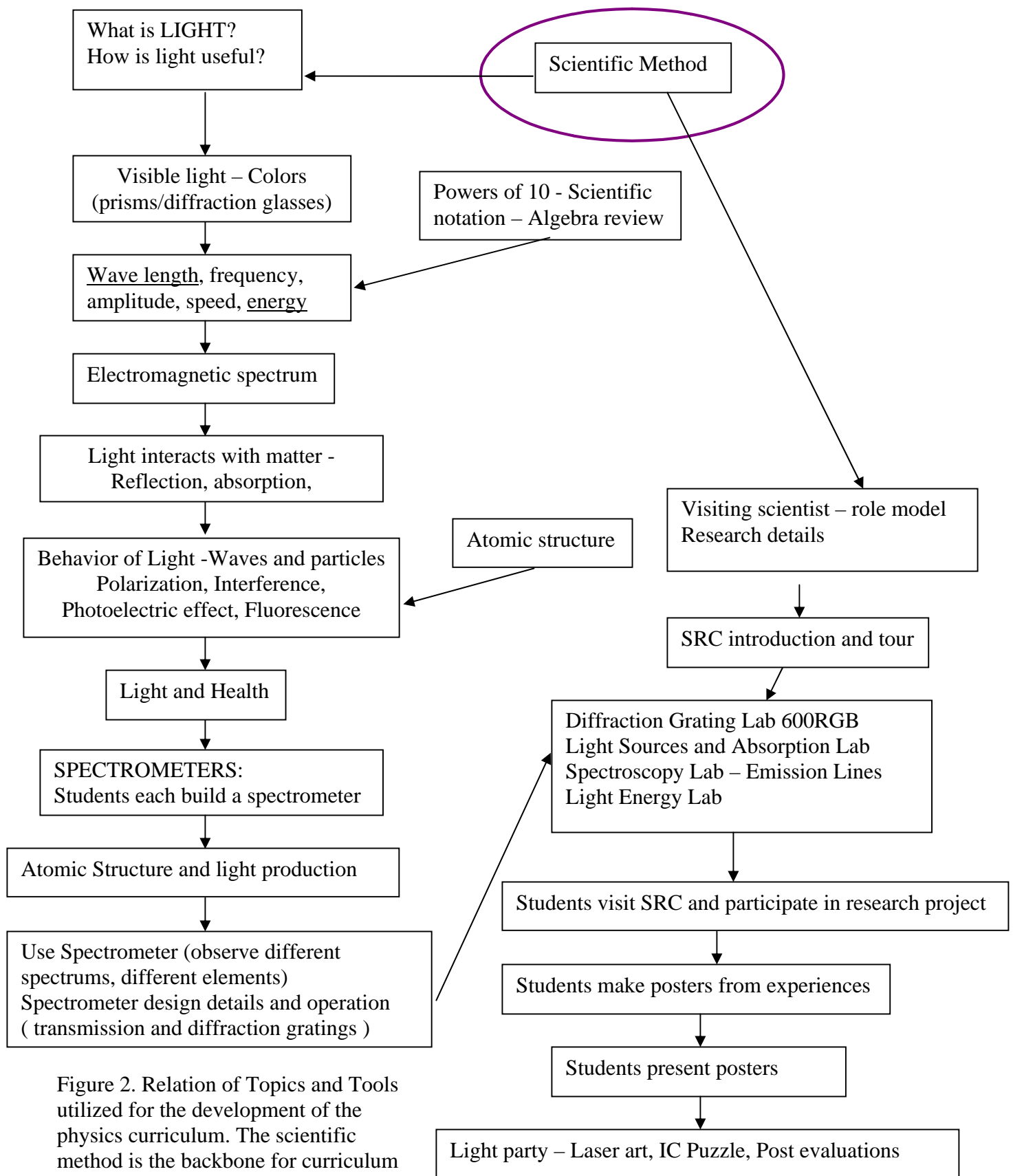


Figure 2. Relation of Topics and Tools utilized for the development of the physics curriculum. The scientific method is the backbone for curriculum development.

*Suggestions for Curriculum Revitalization:*

There are a number of modifications that could be made in a course like this to enhance students' understanding of the NOS. In light of the BPCD (Table 3) teachers can develop student-centered activities that not only serve for pupils to better understand science, but also aid them to effectively appropriate and make use of scientific knowledge. In this section I provide some ideas for the "Let the Light Shine" curriculum revitalization.

To further strengthen the importance of *empirical evidence* in the elaboration of science, instructors can have students gather data from the demonstrations performed in class. It would be helpful to guide students in the recording of particular information in their notebooks. This task should be followed by group discussions and analysis where students have the opportunity to interact and share their observations. Also, students should be asked to draw their own conclusions and discuss them within and among the different cooperative learning groups. It is important that teachers listen and moderate students' interactions. For example, by having students fill in a comparative chart that describes the colors of the substances that burn in the flames (Day 10), pupils can compare their gathered information to the known colors they observed in the lamps on Day 6 using their spectrometer. By doing these comparisons, students should be able to determine by themselves what substances are present in the flame test and experience the data intake and analysis of empirical information that occurs during scientific research.

Additionally, to enhance the focus on the tentativeness of science, it is important that when teachers approach the history of science students are encouraged to compare and

contrast the different times in history and the works performed in each period. Besides discussing the findings of Greeks, Democritus, Copernicus, Kepler, Galileo and Isaac Newton, teachers can also apply constructivist pedagogy by inquiring and helping students point at similarities and differences in regard to light research. By providing cooperative learning groups with guidelines for the investigation of scientists' biography and research, students can summarize their findings in posters and give mini-presentations to share scientists' biographies and research with the rest of the class. Afterwards, it will be useful to have students discuss, compare, and analyze the social and cultural conditions of the different times in history that framed the development of scientists' work. For this, while students present their posters and give the gathered information, an abstract of the milieu characteristics can be filled by other students or the teacher to compile this particular information and have it visible for all the class members. The different methods used to examine light, and the way in which scientists scaffolded their studies onto previous scientists' ideas are also important points that should be brought into class discussions to help students understand that scientific knowledge is *tentative*. Furthermore, teachers can design individual cards with schemes of the different atomic models that have been proposed by the Greeks, Dalton, Bohr, Rutherford, Chadwick, and current scientists (A. R. Irwin, 2000). By providing cooperative learning groups with these diagrams, students should be able to identify and discuss the differences among the models, like the structure, layers, and kind of particles among others. At the end, students can complete a comparative chart to demonstrate and contrast how what some scientists proposed to be truth at one point in time was generally

accepted by the community at that time, and by having these ideas re-evaluated and pursuing further investigations these truths were changed.

In order to have students understand that there *is no one way to elaborate* science, teachers should describe diverse methodologies that different sciences and scientists use along the development of their investigations. Instructors of this physics class could use the different experiments that are performed at the end of the beam lines, as an example of the methodologies used at SRC. Although many of the activities scientists perform at SRC have common procedures, such as the use of light in a particular way, some parts of the research are different, like the way samples are obtained and the different analyses that are performed. Teachers can share two or three research methodologies and have pupils find the commonalities and the differences. Another modification that would address the different ways of doing science can be implemented during Day 10 when teachers present the flame tests as a way to test water for pollutants. Teachers can ask students about other ways to identify contaminants into the water and provide readings that present pupils with study cases where different methodologies are used. After doing their readings, students should be able to share their ideas within cooperative groups and further class discussion should be fostered for students to become aware that there are other ways of carrying out identification of contaminants into the water. After participating in these kinds of activities, pupils should be able to recognize that there is *no one way to elaborate* science.

For the “Let the Light Shine” curriculum it is key to have students become aware that WMS is *a way of knowing* about the world. To address this, some knowledge about indigenous beliefs becomes useful. The “Let the Light Shine” curriculum offers a clear opportunity to familiarize students with non-western approaches when discussing the work of Copernicus, Kepler, and Galileo (Day 2). The western explanations about the origin and dynamics of the universe can be contrasted with the traditional views of Indigenous people. For this, teachers can facilitate an activity where they first ask their students about the traditional stories they know about the formation of the universe. Students should be encouraged to contrast the WMS explanation with the non-western ones; teachers need to point at the homogenizing effect that WMS has on our world and open the class for discussion. Pupils need to be provided with different opportunities to understand that the WMS’ power makes it difficult to realize other ways to explain the phenomena that surrounds us (Harding, 1994). To wrap up, the elaboration of comic strips that combine these different approaches about the world can help students to put together these different ways to explain the same phenomena of the universe.

Not only is thinking about the NOS when developing curriculum important, but making use of different instructional strategies for the development of the classroom activities is also essential (Forawi, 2000). Inquiry-based activities that make the course student-centered are key for pupils to develop a better understanding of the NOS. Teachers should look for additional activities and ideas to make this physics curriculum revolve more around students and boost their critical thinking skills. For example, during Days 3 and 5 teachers can show representations of various waves that have different

characteristics. For this, instructors can give students slinkies of varied sizes, or pictures that model waves with different characteristics. Students can compare and contrast the different waves' representations and teachers can guide students to point at their general characteristics, similarities and differences. This activity can be combined with a handout where students can individually record their observations and then within their cooperative learning groups they can develop and explain their comparisons among the waves. Students might use different words to describe these similarities and differences, but the vocabulary (frequency, amplitude, wave lengths, transverse and longitudinal) can be introduced by having students share their observations in an open class discussion.

Additionally, the incorporation of guides to be filled by students before, during, and after demonstrations can be of great aid. For example, along with the instruction of light's properties (Day 5), instructors can have students take notes on the phenomena they are observing and then encourage the generation of groups' definitions. To re-enforce this topic, the use of electronic instructional materials can be of great aid and further discussion can take place by sharing different perspectives of the issue within groups and with instructors.

Finally, instead of providing reviews at the beginning of the classes, teachers and students would be better served by eliciting students' understanding of previous content. Different activities have the potential to serve this purpose. For instance, a daily contest where students spend 10 minutes individually creating a concept map so they need to use the knowledge they have just studied can be implemented. It would be expected that

throughout critical thinking and metacognitive processes students are able to create accurate maps that evidence their understanding of the themes studied in class. The concept maps should be collected and evaluated by instructors, some award or recognition for the most complete and accurate can be given at the beginning of the next class, and then provide students with a new challenge that encourages children to review the material on their own to better master it.

In the previous curriculum analysis, particular recommendations were given for the enhancement of the “Let the Light Shine” curriculum. Nevertheless, it is important to keep in mind that this workshop is developed under time constraints. It might be too ambitious to try to implement every recommendation at once; changes should be made according to the instructors’ comfort and skill, classroom needs, and changing characteristics of each year. It would be valuable to analyze and evaluate how these different ideas work under the particular conditions of the physics workshop.

### **Conclusion**

It is a fact that the aforementioned academic debates will continue as long as we are concerned with finding more effective and accurate ways of educating our students for a better understanding of the NOS. Nevertheless, the general matter of these disputes is too complicated and attempting to bring it directly into the classroom does not seem to be an easy task, nor is it a good idea. It is fundamental that educators find a more practical way of thinking about the NOS when developing curricula. Teachers must find a balance in

their instruction that prevents the exclusion of NOS basic ideas. Using the Basic Principles for Curriculum Development (BPCD) (Table 3) in combination with other curriculum development ideas and pedagogical strategies would likely help teachers accomplish this task.

It is important to convey the outcomes of this project with other teachers and instructors that develop curriculum for the PEOPLE program. By encouraging new and returning instructors to assess the curricula developed in previous years in the light of the BPCD, the PEOPLE program can better contribute to the achievement of its educational goals related to the enhancement of students' understanding of the NOS.

Additionally, the BPCD should be brought not only to teachers and instructors of the PEOPLE program, but also to educators at all levels in schools. This can be achieved by implementing professional development workshops and seminars that better inform teachers about the NOS and also introduces the BPCD as a tool to address the essential elements of science during classroom instruction. Likewise, publishing articles related to the NOS issues not only in academic journals, but also in newspapers and magazines that will reach teachers in the community will aid educators in better understanding the NOS and improving their students' science experiences.

Finally, I want to emphasize that rather than pretending to use these curricular principles as the ultimate tool for science instruction or as a scaffold to develop assessments, the BPCD should be used in combination with other curriculum development ideas and

pedagogical strategies. Gathering together several instruments for curriculum revitalization would likely help teachers meet their students' academic expectations and prepare them to develop improved understanding and attitudes towards science, and ultimately get be prepared to affront the challenges of every day life.

### ***Acknowledgments***

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## APPENDIX 1 Lessons plan

**SRC – PEOPLE program 2006 - LESSON PLANNING**

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Day 1 (120 minutes)

## Concepts to be taught:

- Science is made combining efforts
- Class organization and purpose
- Light is interesting and fun

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## Agenda:

- PEOPLE pre-assessment
  - Class pre-assessment
  - Ice breaker - Introduction about science
  - Students/instructors introduction
  - Class presentation
  - Elicit student's ideas
  - Polarizer Demo
- PEOPLE pre-assessment / Class pre-assessment: Students are given two pre-assessments, one for the PEOPLE program which evaluates their understanding of the nature of science, and one that will help organize students into cooperative learning groups.
  - Instructors talk about science, and what it is. How scientists cooperate with each other to help find answers. Students work in the building of a puzzle. They should realize that putting the pieces together is like joining efforts in the investigation of any scientific phenomena.
  - Introduction of each person: everyone introduces themselves and tell something interesting about their personal experience in academics or life.
  - Instructors give a power point presentation about the class, expectations, goals, and calendar.
  - Instructors elicit students' ideas about light. Some ideas are: - Waves, energy, different forms of it, it is produced in different ways, it can be transformed into heat.
  - Using the overhead projector, show students a demo with polarizers and plastic case. They are able to see different colors shined on the wall.

## Notes:

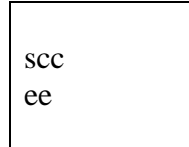
After class instructors should use pre-assessments to organize students into cooperative learning groups.

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Day 2 (120 minutes)

## Concepts to be taught:

- Usage of the scientific method
- Introduction to spectrometers
- Scale concept



## Agenda:

- Group boxes
  - Discussion about light
  - Scientific method: Woolly monkeys investigation
  - CPR: current pickle resuscitation
  - Spectrum of light
  - Movie
- After placing students into the cooperative learning groups provide them with the material box. In there students will find safety glasses, photo cameras, binders where they will be keeping handouts and other materials, notebooks and pencils. Students should know that they will find the materials required for class in that box every day.
  - Discussion about light and how it is useful in our daily live. A little history about light research, beginning with the Greeks, Democritus, talking about Copernicus, Kepler, Galileo and Isaac Newton.
  - Talk about the scientific method, how it is used to do science, and compare it to other ways to inquiry about science. Provide students with a real example using the scientific method: woolly monkey's investigation –
  - Current pickle resuscitation demonstration. Have students question themselves about the nature of the light that is coming out of the glowing pickle. Introduce and use the spectrometer to measure the wavelength of that light. Give students some time to discuss the observed phenomena.
  - Introduce students to the spectrum of light. Using a prism get the rainbow shinning into the wall and with the help of students using mirrors mix the colors together to obtain white light. Use hand out Light and colors. Have students share their observations.
  - Present the movie “Powers of ten” to introduce the scale concept and the importance of scientific notation.

Day 3: (120 minutes)

## Concepts to be taught

- Waves characteristics
- Scientific notation

## Agenda:

- Review about scientific method
- Waves / oscilloscope demo
- Scientific notation
  
- Using the questions stated at the beginning of the class about light, (Day 1), ask students to review the usage of the scientific method.
- Lecture about waves. Waves characteristics → frequency, amplitude, wavelength
- Students get to see waves produced in the oscilloscope, and get to play with it doing “music”.
- Math review. Exponents’ properties, scientific notation.

Day 4 (120 minutes)

## Concepts to be covered:

- Electromagnetic spectrum
- Health and light

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## Agenda:

- Review
- Electromagnetic spectrum
- Sunlight and Health
- Reading and discussion
- Sunscreen activity
- Break
  
- Review about scientific method, math summary, and waves characteristics.
- Electromagnetic spectrum instruction:
  1. Analyze the term electromagnetic spectrum.  
Spectrum means a range of values (energy, frequency, wavelength).  
Electromagnetic describes this type of radiation because light results from interacting electric and magnetic fields.
  
  2. Show visible spectrum on wall again with projector and prism to remind students of what they’ve seen previously.  
Red end fades away into darkness. Purple end fades away into darkness. Are these colors the limits of light?  
Look at the wavelengths and associated colors previously recorded on wall.  
Purple end went down to about 430 nm, and the red end went up to about 655 nm.

3. Look at other examples of light that we've seen in class.

The light emitted from the pickle has peaks at 590 nm (which corresponds to orange-yellow light), at 770 nm, and at 820 nm. What are the colors at 770 and 820 nm? We can't see these wavelengths because our eyes don't detect them. Look at spectrum from a black light with the computerized spectrometer and project onto wall. Notice that this light looks dim. This spectrum shows radiation that our eyes don't see but shows up easily with the spectrometer. Look at radiation emitted by a remote control. It emits longer wavelengths than our eyes can see.

Demonstrate a radio.

All these examples of radiation cannot be detected by our eyes.

4. What other kinds of light are there that are not visible. Pretest answers that students wrote.

Show whole EM spectrum on power point slide. How do all these kinds of radiation differ?

Refer to health effects. Radio, microwaves, visible light, IR we don't have to worry about. They are generally not dangerous. But UV, X rays, and gamma rays are dangerous because they transfer more energy.

All these kinds of radiation differ by energy, frequency, and wavelength, but they all can be described by the same mathematical relationships.

speed of light =  $c = \text{freq} \times \text{wavelength}$ , Energy = a constant  $\times$  freq,

Energy = constant/wavelength

5. Sample calculation.

An AM radio station broadcasts at 970 kHz. What is the wavelength of its radio waves?

k means kilo or  $10^3$ , so 970 kHz is  $9.70 \times 10^5$  1/sec = freq.

$c = \text{freq} \times \text{wl}$ , so  $\text{wl} = c/\text{freq} = 3 \times 10^8 / 9.7 \times 10^5 = 309$  meters.

- Elicit Students ideas (10 min)

On the board write the answers for the following questions

1. In average, how many hours a day do you spend under the sun during summer time? \_\_\_\_\_
2. Multiply that by 90 ( days in 3 months of summer season) \_\_\_\_\_. This is in average the amount of time you spend under the sun in a year, with out taking into account sunny days during spring and fall.

Divide the board in two columns, one for good facts about sun light, one for bad facts about sun light. Ask students their ideas and write them on the board.

- Reading and discussion (15 min)

Give each group a reading about light and ask students to pull out the most important facts they find in the reading. Open discussion asking students to share what they found in their readings with the rest of the class.

- Light Therapy
- Skin cancer
- Vitamin D fixation and bone growth
- UVA & UVB

- Sunscreen activity (25 min)

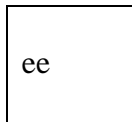
Implement sunscreen activity to test how effective sunscreen is to block UV light. Conclude laying out safety measurements that need to be taken in order to enjoy the outdoors and prevent health problems. Talk about cloudy days and how UV rays trespass clouds and reach our skin. Give them UV sensitive bead's bracelets to help them be aware of light radiation.

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#### Day 5 (120 minutes)

Concepts to be covered:

- Properties of light
- Spectroscopy



Agenda:

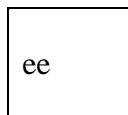
- Review
- Properties of light
- Spectrometer

- Review about waves' amplitude, how they add and the different kinds of waves. Remind students about the types of waves, transverse and longitudinal, and also about the importance of having a material or medium for the waves to propagate a disturbance to have them originate.
- Instruction about absorption, reflection and transmission
- Polarization demonstration. Students get the chance to play with polarizer and filters
- Introduction to the spectrometer. How it works, how it is used. Students get to build their own spectrometer

#### Day 6 (120 min)

Concepts to be covered:

- Use of a spectrometer
- Why do different sources of light have different colors?
- Atomic structure



Agenda:

- Schedule review
- Using the spectrometer
- Atomic structure

- Spectrometer activity

- Relation of wave length, frequency and energy
- Atomic structure

1. When you looked at the different light sources with your spectrometers, what did you see?

The light—meaning the visible colors or wavelengths—given off by each light source is different. The spectrum emitted from the helium lamp is distinct from the spectrum from krypton is distinct from the spectrum from sodium. Each element emits a unique set of wavelengths of light. To understand why these atomic spectra are all different, we need to look at atomic structure. The main idea is that atoms absorb or emit light when their electrons move around in different energy levels.

2. How are electrons arranged in an atom?

There are 3 types of particles in an atom: protons (+ charge), neutrons (0 charge), and electrons (- charge). The protons sit in the center of the atom as the nucleus, and the electrons are surround the atom in wispy clouds. It is impossible to precisely locate the electrons, but their energy level can be determined precisely, and it's the energy level of electrons that we're interested in.

The central point is that the positive charge is in the center and negative electrons surround it, and remember that negative and positive electrical charges attract one another. The electrons are held close to the nucleus because of the electrical attraction.

3. The energy levels of electrons are distinct or separate (quantized).

If we look at a ball rolling down an inclined plane as in everyday physics, the potential energy (PE) of the ball can be calculated by

$PE = \text{gravitational force} \times \text{mass} \times \text{height of ball above ground}$

The gravity and mass are constant, so the PE of the ball depends on its height above the ground. It looks like the ball should have an infinite number of potential energy levels because there is an infinite number of positions it can take along the plane.

The energy levels of electrons in an atom do not look anything like this picture from everyday physics. They cannot take just any energy level, but there are only specific energy levels that an electron can take. So we have to replace our inclined plane picture with a staircase, each step representing a specific energy level. It's as if our ball can only have energy levels equivalent to the steps on a staircase. The ball can be on one step or another, one energy level or another, and there is no in between energy levels possible. On the atomic scale, energy is not sub divisible as it appears to be on an inclined plane. Energy comes in specific packages or quantities, with no intermediate values possible. The main point is that the energy levels of electrons can only take specific values; they are distinct.

4. The energy level of an electron in an atom is related to its distance from the nucleus. It is analogous to gravity again. If an electron moves away from a nucleus, it must gain energy to do so because it is moving away from or against

the attractive force of the positively charged nucleus. The electron thus gains potential energy; it then sits at a higher potential energy. Conversely, when an electron moves closer to a nucleus, it is losing energy because it follows the attractive force. It decreases in potential energy or sits at a lower energy level. The energy levels of an electron in an atom are designated by  $n = 1$ ,  $n = 2$ , or  $E_1$ ,  $E_2$ , etc. An electron that moves from  $E_1$  to  $E_2$  absorbs or gains energy; an electron that falls from  $E_3$  to  $E_2$  or  $E_1$  loses or gives off energy.

5. When an electron changes its energy level in an atom, it can give off or absorb light.

How does an electron gain energy to move up to a higher energy level? It can absorb energy as heat or electrical energy or light. Atoms and molecules absorb light because one or more of their electrons absorbs the light energy to move to a higher energy level. But there is an important restriction on this absorbance of light energy. The energy that an electron must absorb to move to a higher energy level must be exactly matched by the energy of the light that it absorbs. If the match is not exact, there is no absorbance. For example, if the energy difference between two possible electron levels is 10 eV, light with 9 eV can't be absorbed by an electron. There simply isn't enough energy to get the electron into the higher energy level. But the strange thing is that if some incoming light has energy of 12 eV, it is also not absorbed. Even though it has enough energy to get the electron to the 10 eV higher energy level, the energy of the light must be all absorbed, or none of it is absorbed. The energy of the light cannot be subdivided. The 12 eV light cannot give up 10 eV to boost the electron up and yield an extra 2 eV left over. This fact that the light energy cannot be divided up is evidence for light acting as a particle (photons of light). So the important point is that for if an electron is to move to an energy level that is 10 eV higher, it can absorb only light that has 10 eV of energy. It will absorb no other energy of light. That's why atoms or molecules only absorb specific energies or wavelengths of light.

6. Emission of light energy by electrons follows the same patterns as absorbance of light energy, it's just in reverse.

If an electron falls from a higher to a lower energy level, it loses energy, and the energy it loses is given off as light. The energy of the light given off is the same as the energy difference in the electron energy levels. So if an electron falls from  $E_3$  to  $E_1$  in one step and decreases in 8.3 eV in that change, it will give off light with exactly 8.3 eV. If it falls from  $E_3$  to  $E_2$  (2.2 eV) then from  $E_2$  to  $E_1$  (6.1 eV) in two distinct steps, it will give off light with 6.1 eV and 2.2 eV. Again, the energy change of the electron must exactly match the energy of the light emitted. And the energy is related to the wavelength of light by  $\text{Energy} = \text{constant}/\text{wavelength}$ . Each energy change of an electron thus emits light of specific wavelengths.

7. Each element has atoms with a unique number of electrons and so unique sets of electrons. The light an atom can give off depends on its electrons. So each element gives off a specific set of wavelengths of light because it has a unique set

of electrons. That's why the sodium lamp, krypton lamp, etc. all have unique colors or emission spectra.

- Handout about atomic structure

Day 7 (120 minutes)

Concepts to be covered:

- Scientists are valuable part of the society

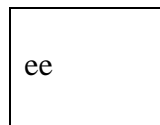
Agenda:

- Seminar: Visiting Scientist

Day 8 (160 minutes)

Concepts to be covered:

- Synchrotron Radiation Center (SRC)
- The use of light at the SRC



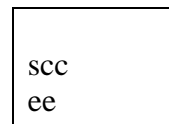
Agenda:

- Field trip
- Students are taken to the research facilities of the Synchrotron Radiation Center (SRC) for an introduction to the place.
- Monochromator instruction

Day 9 (120 minutes)

Concepts to be covered:

- The use of team work for research



Agenda:

- Questions
- Research experiments
- Ask students about any questions they might have after their visit to the SRC.
- Ask students to formulate a question about their visit to the SRC
- Organize students into their groups and explain to them how they need to work cooperatively in order to carry out the research experiments for today and tomorrow.

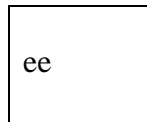
Day 10 (120 minutes)

Concepts to be covered:

- Different elements give off different kinds of light

## Agenda:

- Field trip review
- Research experiments
- Flame test



- Review with students the plan for the last field trip to the SRC. Remind them that they will be working with scientists and taking data. Ask them to bring notebooks and cameras to record their experiences.
- Discuss about how scientists work together to do scientific research.
- Switch groups to work into the lab experiment that they need.
- Flame test

## 1. How do atoms emit light?

Remember, atoms emit light when they absorb some energy that boosts one or more of their electrons into a higher energy level. When that electron spontaneously falls back to a lower energy level, it loses energy, and that energy is given off as light. An atom may absorb energy in different kinds of ways. It can be heated up (like the filament in a light bulb). It can absorb electrical energy (like the LEDs used in the Spectrometer lab).

## 2. Look at periodic tables, because we'll look at several elements on it.

3. Because each different kind of atom (atoms of different elements) has a unique number of electrons or a unique set of electrons, its electrons all have energies distinct to that kind of atom.

The electron energies of sodium, for example, have different energies than the corresponding electrons in potassium. When an electron falls from a higher to a lower energy level, the light energy that electron emits is specific to the difference in energy of the energy levels of that atom. So because the energy levels of sodium are different than those of potassium, its electrons will emit light that is distinct from that of potassium. In fact, because the atoms of each element have a unique set of electrons, each element will emit a unique set of energies (or wavelengths or colors).

## 4. Demonstration.

Heat a wire with various salt solutions in a hot burner flame. The flame glows a color that is characteristic to the element. Elements (metals used)/color generated:

sodium/orange (same color as the sodium lamp)

potassium/purple

lithium/red

copper/green

boron/green (more yellowish green than copper)

strontium/red

barium/green

5. There are two applications of this phenomenon that atoms emit and absorb specific wavelengths or colors of lights. See the accompanying handouts.
- A. The bright colors of fireworks are produced by salts of various metals getting heated up as the fuel of the fireworks burns.
  - B. Metals can be detected in very small quantities by a technique known as flame atomic absorption (or just atomic absorption, AA). A current application of this technique is the measurement of the metal manganese in the Madison water supply.

A sample of water is heated in a burner to a high temperature, and a beam of light is sent through the flame. The beam of light is generated by lamp that contains the metal of interest, manganese, for example. That manganese beam will therefore be composed of wavelengths specific to manganese. A detector on the other side of the flame measures the intensity of the light coming through the flame. Any manganese atoms in the water sample will specifically absorb the light from the manganese lamp used to generate the light. The detector can measure the difference in intensity of the light before and after it passes through the flame. Any manganese in the water (and flame) will absorb some of the light and so decrease its intensity. The machine can then be used to measure the concentration of the manganese in the water sample because there is a simple, linear relationship between the concentration of manganese in the water sample and the quantity of light absorbed by the flame.

Day 11 (200 minutes)

Concepts to be covered:

- Understand how scientists use light to do scientific research
- Recognize and experience how scientists use team work

Agenda:

- Field trip to the SRC

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- Students are taken to the SRC for lunch with scientists.
- After lunch the class is divided into the cooperative learning groups, and each group works with a scientist from the SRC taking data at the end of a beam line.

Day 12 (120 minutes)

Concepts to be covered:

- The importance of communicating scientific findings

Agenda:

- Poster work

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- Students are given some guidelines in regard of poster preparation.
- Students work into their cooperative learning groups to prepare their posters.

Day 13 (120 minutes)

Concepts to be covered:

- Different atoms emit different spectra
- What is the pickle made of?

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Agenda:

- Review
  - Question
  - Atom's glow observations
  - Poster work
- Review with the students about the Scientific Method, step by step
  - Ask students what is light. Come up with a definition: Light is light – light is energy that is transformed through space by photons that behave like particles (rays) or waves (transverse wave that can be polarized)
  - Discussion about how light is produced.
  - Have students observe different spectra of different atoms and relate them to their position in the periodic table. Students should be able to identify the atom that makes the pickle glow
  - Students go back to the poster to finish them for their presentation. Each individual of the group should be prepared to answer questions.

Day 14 (120 minutes)

Concepts to be covered:

- The value of scientific research and the importance of communicating it.

Agenda:

- Posters presentation
- Light art
- Post assessments
- Ice cream puzzle

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- Students present their posters to the rest of the class and answer questions about the research they carried at the SRC
- Divide the class into two groups. One group will be playing with lasers to create a laser art piece. The other group using the overhead projector observes different objects in between polarizer.
- Students answer the post-assessment for the class and for the PEOPLE program. The post-assessment of the class is evaluated to give students some feedback about their improvement in the subject of light.
- Students work in the recognition of the spectra for different ice cream flavors, and at the end get to eat different ice creams and toppings.

## APPENDIX 2 Pre-assessment

SRC – PEOPLE program. **Let the Light shine!**

\_\_\_\_,\_\_\_\_,2006

Name: \_\_\_\_\_

**WELCOME to the SRC Team!**

We are really excited to work with you this summer time. The course that you will be taking for the following weeks has been organized by Scientists and Educators who want to facilitate your learning process. For this reason we need you to answer some questions in advance that will help the instructors not only to accommodate the lessons for your better understanding of the topic, but also to evidence your progress at the end of this experience.

Please answer the following questions, if you are not sure about the answer please indicate it by underlying the (not so sure) option, but also try your best.

1. An atom is the smallest structure of all mater, but it is composed by three particles. Can you please draw a picture of an atom showing its structure and the location of these particles? (not so sure)
  
  
  
  
  
  
  
  
  
  
2. Take a moment and think about light, then answer the following questions:
  - a. What is light for you? (write a definition) (not so sure)

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b. Which are the characteristics of the light? (not so sure)

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c. How does light interact with matter? (not so sure)

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3. a. Do you know what a computer spread sheet is?( You can think of EXCEL, the computer's program, which is an example) \_\_\_\_\_ (not so sure)

b. If yes, Do you know how to use it to manipulate data (numbers in general) to create graphs? \_\_\_\_\_ (not so sure)

4. Using the calculator can you find the value for the following equation? (not so sure)

a.  $Y = \sin 45$

b.  $Y = \sin 63$

c.  $Y = \sin 27$

d. What is behind this concept? (not so sure)

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5. Please write the following numbers using decimal numbers. (not so sure)

a.  $10 > 8$ : \_\_\_\_\_ b.  $10 > -11$  \_\_\_\_\_

6. In a radio station different programs are broadcasted every day. Do you now how your favorite program gets from a radio station to your radio? \_\_\_\_\_ I you know, please briefly explain. (not so sure)

7. At the SRC, different investigations are going on while we are having this class. Because you will be experiencing a real scientist life experience, we want to accommodate you with a team of scientists who are working in something that you find interest interesting. Please rank the following topics from 5 to 1

\_\_\_\_\_ IR studies of Alzheimer's tissue (Infrared studies of brain tissues)

\_\_\_\_\_ High Tc Superconductor investigations (Study energy bands in metals using X-rays)

\_\_\_\_\_ The Fingerprints of Space (Studies of X-ray absorption by gases)

\_\_\_\_\_ Conduction properties of Supercritical Fluids (VUV studies of rare gases with impurities)

\_\_\_\_\_ Spectromicroscopy of cells (using x-rays and spectrometer-microscope combination to study biological cells)