

The HS Lab Experience: Reconsidering the Role of Evidence, Explanation and the Language of Science¹

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Introduction

The purpose of this paper is to examine the role of laboratory-based science from a perspective that synthesizes developments in (1) science studies, e.g., history, philosophy and sociology of science and (2) the learning sciences, e.g., cognitive science, philosophy of mind, educational psychology, social psychology, computer sciences, linguistics, and (3) educational research focusing on the design of learning environments that promote dynamic assessments. Taken together these three domains have reshaped our thinking about the role inquiry, and in turn the laboratory, has in science education programs. Over the past 50 years there have been dynamic changes in our conceptualizations of science, of learning, and of science learning environments. Such changes have important implications for how we interpret (1) the role of inquiry in K-12 science education programs and (2) the design of curriculum, instruction, and assessment models that strive to meet the NSES inquiry goals: Students should learn to do scientific inquiry; Students should develop an understanding of scientific inquiry

Since the first NSF funded era of science education reform in the 1960s and 1970s, there have been radical changes in our thinking about the nature of science, the nature of learning, and the nature of science teaching. In general we see a shift from science as experimentation to science as explanation/model building and revision; from learning as a passive individualistic process to learning as an active individual **and** social process; from science teaching focusing on the management of learners' behaviors and "hands-on" materials to science teaching focusing on the management of learners' ideas and use of information. Many of the changes have been motivated by new technological development but new theories about learning have contributed to the changes, too.

One important change that has significant implications for the role of the laboratory in high school science concerns the realm of scientific observations. New technologies and new scientific theories over the last 100 years have changed the nature of scientific observation from a *sense perception* dominated enterprise to a *theory-driven* supported enterprise. That is, what we see is influenced by what we know, the application of scientific theories to the design and interpretation of observational methods. New technologies and learning theories also have changed how we engage learners for purposes of monitoring, diagnosing and nurturing learning. For example, scientific databases like Geographical Information

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Systems (GIS) make it possible to engage in rich scientific inquiry without engaging in hands-on science involving the collection of data. Here the data are provided and the inquiry begins with the selection of information for analysis. This is one example of how science education has shifted from management of materials for collecting data to management of information for scrutinizing databases. Information in the guise of data, evidence, models and explanations represent, in an important sense, the new materials for high school laboratories. Taken together these changes in technologies and theories have implications for how we conceptualize the design and delivery of science curriculum materials for purposes of supporting students' learning as well as teachers' assessments for promoting learning.

The evolution of ideas about the nature of science, in particular the relation between observation and theory, has not had a significant impact on current practices regarding the role of laboratories in high school science. The research literature indicates a long standing struggle regarding the integration of nature of science perspectives into school science. [insert from Osborne, et al]. The tension that exists is characterized as that between expectations of learning about what we know versus expectations of learning about how we know and why we believe. In terms of the NSES content standards, the emphasis in high school science programs seems to be squarely grounded to only 4 of the 8 NSES content standards. That is, the emphasis is on the subject matter standards (e.g., physical sciences, life sciences, and earth & space sciences) and the inquiry standard. Less emphasis is put on the remaining content standards; e.g., Unifying Concepts and Processes, Science and Technology, Science in Personal and Social Perspectives, History and Nature of Science. I would argue that this is fundamentally the result of expectations and values found in extant curriculum frameworks and assessment practices (Gitomer & Duschl, 1998).

The sentiment held by many classroom teachers is that science concepts must be taught directly as opposed to science concepts being selected and embedded in instructional sequences that require knowledge- in-use as an element of learning (Krajick, et al xxxx) or formative assessments as an element of teaching (Harrison, Black, Osborne & Duschl, 2004; Black, 2003; Duschl, 2003, Shepard, 2000). Missing from the high school science curriculum landscape are new models of curriculum that place science learning in historical, contemporary, technological, social and personal contexts. While there are some important advances being made in curriculum design (e.g., the NSF Center of Teaching and Learning consortium of AAAS, University of Michigan, Michigan State University, and Northwestern University and the UK's 21st Century Science initiative), school programs have been slow to embrace such innovations. A probable reason is the expectations such curricula require with respect to the application of learning science principles to both instructional and assessment model. Another reason derives from teacher and parent beliefs and expectations of what constitutes a proper science education, particularly in terms of those students pursuing science as a major in college.

Sustained and systematic teacher professional development is needed to educate teachers and stakeholders (e.g., parents, principals, school board members) about new research-based models of curriculum, instruction, and assessment that effectively promote science learning and science communication. The AAAS-Michigan-MSU-Northwestern CTL consortium plans include some

professional development but more is needed, of course. And, importantly, the character of the continuing professional development (CPD) needs to adhere to what research informs us are elements of effective CPD: CPD must be situated in the problems teachers encounter; CPD must be sustained for long periods of time, 2-3 years minimum; CPD must follow teachers back into classrooms and thus have a coaching component.

The advancement of computer-supported instrumentation, information systems, data analysis techniques or in general scientific inquiry practices has created a problem though. The language of science in schools and in the media has not kept pace with the language of scientific practice; a practice that is decreasingly about experiments and increasingly about data and data modeling. In brief, one could argue that causal explanations grounded in control of variable experiments have given ground to statistical/probabilistic explanations grounded in modeling experiments. The language of science in each experimental context is different. A reconsideration of the role of laboratory in high school science must address closing this language gap and herein lays the importance of promoting scientific discourse practices. Examples of newly designed inquiry curriculum sequences that are striving to address the language gap include the LETUS program at Northwestern, the Learning By Design program at Georgia Tech, the SCOPE program at Berkeley and University of Washington, the WISE program at Berkeley, and the MUSE program at Wisconsin, among others. *These initiatives are research based programs. Scaling up for board implementation will require changes in teachers' perspectives and beliefs about critical science learning objectives and characteristics of effective science learning and teaching. A strong push is needed to inform teachers, parents, and school boards and administrations about the new learning sciences research.*

The inquiry sequence approaches have adopted a model of science instruction that situates learning within design, problem and/or project contexts. The design, problem, or project based immersion units represent 4-6 weeklong lesson sequences that are situated within a compelling context to motivate students and to advance rigorous learning. Furthermore, in order to support learning, the immersion units typically contain tasks that help make students thinking visible and thus provide teachers with valuable insights about how to give feedback to students. The commitments are to promoting the communication of scientific ideas, to the development of scientific reasoning and to the ability to assess the degree of legitimate doubt that can be attached to scientific claims. The intent is to assist learners with both the construction and the evaluation of knowledge claims. Thus, by design, students are given extended opportunities to explore the relationship between evidence and explanation. *To this end, labs are situated into longer thematic instructional sequences, where the theme is defined not by the conceptual structures of science alone. Rather, the sequence of lab investigations is designed to support acquisition of evidence as well as language and reasoning skills that promote progress toward a meaningful inquiry goal; e.g., the design, problem or project. The shift from a content/process focus of science education to an evidence/explanation focus has significant implications about the role of the laboratory in high school science.*

The lesson sequence approach, referred to as full-inquiry or immersion units, stands in stark opposition to single lesson approaches that use lab investigations to partition concepts and processes. Osborne and Freyberg (1985) report that students' understandings of the goals of lessons do not match teacher's goals for the same lessons. When students do not understand the goals of experiments or lab investigations, negative consequences for student learning occur (Schauble, Glaser, Duschl, Schulz & John, 1995). Unfortunately, the single science lesson approach is the dominant practice found in schools. By situating science instruction and learning within a design-based, problem-based, or project-based context, to which members of the class have both individual and group responsibilities, a very different classroom learning environment or culture develops.

When we synthesize the learning sciences research (c.f., Bransford, Brown & Cocking, 2000; Pellegrino, Churkowsky & Glaser, 2002), the science studies research (c.f., Giere, 1988; Hull, 1988; Longino, 2002; Magnani, & Nersessian, 1999) and science education research (c.f., Millar, Leach & Osborne, 2001; Minstrel & Van Zee, 2001) the messages we receive are:

(1) The incorporation and assessment of scientific inquiry in educational contexts needs to focus on three integrated domains:

- The **conceptual** structures and cognitive processes used when reasoning scientifically,
- The **epistemic** frameworks used when developing and evaluating scientific knowledge, and,
- The **social** processes and forums that shape how knowledge is communicated, represented, argued and debated.

(2) The conditions for science inquiry learning and assessment improve through the establishment of:

- Learning environments that promote **student centered learning**,
- Instructional sequences that promote **integrating science learning** across each of the 3 domains in (1),
- Activities and tasks that **make students' thinking visible** in each of the 3 domains, and
- Teacher designed assessment practices that **monitor learning and provide feedback** on thinking and learning in each of the three domains.

The basic argument is that full inquiry or immersion units make possible the meaningful learning of difficult scientific concepts, the development of scientific thinking and reasoning, the development of epistemological criteria essential for evaluating the status of scientific claims and the development of social skills concerning the communication and representation of scientific ideas and information. Providing students with opportunities to link evidence to explanations is vital. Hence, science 'laboratory' experiences are essential. In the sections to follow, I will examine, in turn, how research from the science studies; the learning sciences, and educational research argues for the reconceptualization and reorganization of science laboratory instruction.

Changing Images of Inquiry

Over the last 50 years, science education in the USA has been a strong focus of attention. In the 1950s, following on from World War II, steps were taken to ensure the scientific superiority that contributed to winning the war would be sustained. New technologies and new frontiers of science defined post-war America and in order to keep our technological and scientific edge the general consensus among policymakers was that science education in our precollege schools and classrooms needed changes that would modernize both what was taught and how it was taught.

The task of overhauling high school science programs fell to the same scientists that contributed to our war effort (Rudolph, 2002; Duschl 1990). The goal was to establish a curriculum that would develop in learners the capacity to think like a scientist and prepare for a career in science, mathematics and engineering. Thus, not surprisingly, the initial NSF-funded science curriculum (PSSC, BSCS, CHEMSTUDY) had a ‘science for scientists’ focus of instruction. Embedded within the ‘science for scientists’ approach was a commitment that students should be provided opportunities to engage with phenomena; that is to probe the natural world and conduct inquiries that would reveal the patterns of nature and the guiding conceptions of science. The goal was to downsize the roll of the textbook in science teaching and elevate the roll of the laboratory experience in science classrooms. That is, according to Joseph Schwab (1962), first director of BSCS, science education should be designed so that learning is an ‘enquiry into enquiry’ and not a rhetoric of conclusions, e.g., teaching what we know.

The commitment to inquiry and to lab investigation is a hallmark of USA science education. The development of curriculum materials that would engage students in the doing of science though required an investment in the infrastructure of schools for the building of science labs and for the training of teachers. What is important to note is that at the same time period (1955 to 1970) when scientists were leading the revamping of science education to embrace inquiry approaches, historians and philosophers of science were revamping ideas about the nature of scientific inquiry and cognitive psychologists were revamping ideas about learning. A reconsideration of the role of the laboratory in high school science, it can be argued, began approximately 50 years ago.

Whereas the ‘science for scientists’ approach to science education stressed teaching what we know and what methods to use, the new views of science and of psychology were pressing issues of how we know what we know and why we believe what we know over competing alternatives. The shift was a move from a curriculum position that asks, “what do we want students to know and what do they need to do to know it”, to a curriculum position that asks, “what do we want students to do and what do they need to know to do it”. The NSES content goals for inquiry focus on student’s abilities to do inquiry and to understand the nature of scientific inquiry. But once again we seem to find ourselves in the situation where science education has not kept pace with developments in science. That is, science education continues to be dominated by hypothetico-deductive views of science while philosophers of science have shown that scientific inquiry has progressed to theory building, conceptual change views and model-based views of science. This is not to imply that scientists no longer engage in experiments. Rather, the role of

experiments is situated in theory and model building, testing and revising, and the character of experiments is situated in how we choose to conduct observations and measurements; i.e., data collection. The danger is privileging one image of doing science to the exclusion of others.

Developments in scientific theory coupled with concomitant advances in material sciences, engineering and technologies has given rise to radically new ways of observing nature. Where once science was dominated by sense perception gathering of evidence, today tools, instruments and computers frame the observational processes of science. At the beginning of the 20th century scientists were debating the existence of atoms and genes, by the end of the century they were manipulating individual atoms and engaging in genetic engineering.

These developments have altered the nature of scientific inquiry and greatly complicated our images of what it means to engage in scientific inquiry. Where once scientific inquiry was principally the domain of sense perception and tactile measurements, today scientific inquiry is guided by theoretical beliefs that determine the very existence of observational events (e.g., neutrino capture experiments in the ice fields of Antarctica). Where once science inquiry was principally a quest for new knowledge, today scientific inquiry underpins the research and development of new technologies and of pressing social problems, e.g., feeding an exploding world population through GM food technologies; requiring MMR shots to all new born infants. Looking back there are several trends in science education that have altered our images of the role of the laboratory in science education:

- From an image of science education for scientists, to science education for all.
- From an image of science education to teach what we know, to science education to teach science as a way knowing.
- From an image of science education that emphasizes content & process goals to science education that stresses goals examining the relation between evidence and explanations.
- From an emphasis on individual science lessons that demonstrate concepts, to science lesson sequences that promote reasoning with and about concepts.
- From the study of science topics that examine current scientific thinking, to the study of science topics that examine science in social contexts.
- From a view of science that emphasizes observation and experimentation, to a view that stresses theory and model building and revision.
- From a view of scientific evidence principally derived from sense-perception observations, to a view that evidence is obtained from theory-driven observations.

The implications for the role of laboratory in high school science are significant since these changes raise questions about (1) the extent of lab time allocated to interactions with basic scientific phenomena; (2) the depth and breadth of experiences learners bring with them to the science classroom; and (3) the kind of phenomena and experiences that stimulate science learning. As stated above, the 1960s NSF sponsored revolution in science education focused on a science for scientist approach. Twenty years later after an enormous infusion of scientific knowledge into all walks of life, arguments for a science for

all approach to science education began to emerge. Scientific knowledge was seen as needed for participation in the workplace and in the modern democracy. However, the science education community has been slow to embrace new philosophical, psychological and pedagogical models that can inform the design of curriculum, instruction, and assessment frameworks that, in turn, guide the role of the laboratory in science education.

Science Studies

It is well beyond the scope of this paper to provide a comprehensive review of developments in the science studies. The interested reader can find useful summaries in Duschl (1990, 1995) and in Matthews (1994). In very broad brushstrokes, one can summarize developments along a continuum where science has been conceived as an experiment-driven enterprise, a theory-driven enterprise, and a model-driven enterprise. The experiment-driven view of science emerged out of the fin de siècle activities of the Vienna Circle. The commitment among a group of natural philosophers (e.g., Mach, Carnap, Hempel, Reichenbach) was that science not unlike mathematics should be grounded in logic and comprised of a language that distinguished observational statements from theoretical statements. The enterprise gave birth to analytical philosophy and to the movements called logical positivism, logical empiricism and hypothetico-deductive science. The image of scientific inquiry was that new knowledge accrued to established knowledge. How knowledge was discovered was not the philosophical agenda, only the justification of knowledge was important. This early 20th century perspective is referred to as the ‘received view’ of philosophy of science.

The watershed event for challenging the received view was the 1962 publication of Thomas Kuhn’s *The Structure of Scientific Revolutions (SSR)*. *SSR* challenged the extent to which one could claim either that the growth of knowledge is an accumulative process or that science is an objective and rational enterprise. For the next 40 years, philosophers of science engaged in various attempts to demonstrate how in the face of radical shifts in theory, method and goal commitments, science was nonetheless a rational way of knowing. The emphasis on theory structure and theory change became the core issues of history and philosophy of science (Suppe, 1977). The observational-theoretical distinction was dead. The context of discovery became important. The dialectical processes that shaped what would count as scientific knowledge claims tempered the emphasis on logic and on hypothetico-deductive processes of science.

What came to be recognized and understood through historical and contemporary case studies of scientific inquiry was that the move from experimental data to scientific theory was mediated by dialogic communication. What stands between data and theory are models. Model-based views of the nature of scientific inquiry allow the inclusion of psychological processes where the received view did not. Model-based views recognize that argumentation discourse processes serve to define dialogic communication. By standing between, models can be influenced by both data revisions and changes in theory commitments.

Lab investigations situated in immersion units afford such opportunities for data revision and theory change. Thus, experiment and theory structure are important elements of the nature of scientific

inquiry but now must be understood in relation to the dialectical processes that establish data as evidence and then take the evidence to forge explanations. The implication for high school laboratories is that science education should provide more opportunities that lead to model-based inquiry and support the dialectical processes between data, measurement, and evidence on the one hand, and observation, explanation, and theory, on the other. In such immersion units, students can be enticed to experiment for reasons and reason about experiments.

The Learning Sciences

Conceptualizing model-based science is prompted by cognitive science research demonstrating that higher-level thinking or reasoning is domain specific and specialized (Bransford et al, 1999). Research on learning with an eye toward informing educational processes suggests that we must attend to the development of 4 types of knowledge: declarative “what we know” knowledge, procedural “how we know” knowledge, systemic “why we know” knowledge, and strategic “thinking about thinking” knowledge. Given this richer model of learning we can better appreciate requests that an important dynamic in the science classroom, and all classrooms for that matter, is making students thinking visible. The application of theory change processes to science education developed a focus on conceptual change teaching (Posner, Strike, Hewson & Gertzog, 1982). A consideration for the role dialectical processes have in science and in science learning developed a focus on conceptual change teaching that was embedded both in motivating and relevant curricular contexts and in learning environments that promoted meaningful learning and reasoning (Pintrich, Marx, & Boyle, 1993).

Robert Glaser (1995), in a major review of how psychology can inform educational practice develops and outlines the components of a coherent learning theory that can inform instruction, curriculum and assessment design. He identifies 7 research findings (See Figure 2) that inform us about the structure and design of learning environments – aspects of which are further elaborated in *How People Learn* (Bransford, et al, 1999).

1. *Structured Knowledge* - "Instruction should foster increasingly articulated conceptual structures that enable inference and reasoning in various domains of knowledge and skill" (p. 17).

2. *Use of Prior Knowledge and Cognitive Ability* - "Relevant prior knowledge and intuition of the learner is . . . an important source of cognitive ability that can support and scaffold new learning . . . the assessment and use of cognitive abilities that arise from specific knowledge can facilitate new learning in a particular domain" (p 18).

3. *Metacognition Generative Cognitive Skill* - "The use of generative self-regulatory cognitive strategies that enable individuals to reflect on, construct meaning from, and control their own activities . . . is a significant dimension of evolving cognitive skill in learning from childhood onward . . . These cognitive skills are critical to develop in instructional situations because they enhance the acquisition of knowledge by overseeing its use and by facilitating the transfer of knowledge to new situations . . . These skills provide learners with a sense of agency" (p. 18).

4. *Active and Procedural Use of Knowledge in Meaningful Contexts* - "Learning activities must emphasize the acquisition of knowledge, but this information must be connected with the conditions of its

use and procedures for it applicability. . . School learning activities must be contextualized and situated so that the goals of the enterprise are apparent to the participants" (p. 19, emphasis in original).

5. *Social Participation and Social Cognition* - "The social display and social modeling of cognitive competence through group participation's is a pervasive mechanism for the internalization and acquisition of knowledge and skill in individuals. Learning environments that involve dialogue with teachers and between peers provide opportunities for learners to share, critique, think with, and add to a common knowledge base" (p. 19).

6. *Holistic Situations for Learning* - "Learners understand the goals and meanings of an activity as they attain specific competencies . . . Competence is best developed through learning that takes place in the course of supported cognitive apprenticeship abilities within larger task contexts" (pp. 19 -20).

7. *Making Thinking Overt* - "Design situations in which the thinking of the learner is made apparent and overt to the teacher and to students. In this way, student thinking can be examined, questioned, and shaped as an active object of constructive learning" (p. 20).

Figure 2 - Glaser's Seven Principles of Instruction

Prominent in the components of effective learning environments identified by Glaser is recognition of the important role prior knowledge, context, language and social processes have on cognitive development and learning. Such components are not marginal but centrally important to the process of learning. Such understandings have guided many educational researchers to now conceive of thinking and reasoning as acts that are socially driven (Brown, 1992; Cobb, 1994; Rogoff, 1990), language dependent (Wertsch, 1991; Gee, 1994), governed by context or situation (diSessa, 2000; Brown, Collins and Durgid, 1989) and involving a variety of tool-use and cognitive strategies (Edelson, Gordin, & Pea, 1999; Kuhn, 1999). Putnam and Borko (2000), in an article that examines the challenges these new ideas about knowledge and learning have for teacher education, summarize these newer conceptions of learning respectively as cognition as social (in that it requires interaction with others), cognition as situated (in that it is domain specific and not easily transferable), and cognition as distributed (in that the construction of knowledge is a communal rather than an individual activity). The various programs of research conducted and coordinated by cognitive, social, developmental and educational psychologists now present a more coherent and multi-faceted theory of learning that can inform the design of learning environments (Bransford, et al, 1999). In science education, I interpret this to mean that students must have an opportunity to engage in activities which require them to use the language and reasoning of science with their fellow students and teachers – that is to engage in the construction and evaluation of scientific arguments and models through a consideration of the dialogic relationship between evidence and explanation.

Today, understanding scientific knowledge, developing abilities to do scientific inquiry and understanding the nature of scientific inquiry requires going further than simply learning the conceptual frameworks of science. Thus, the role of laboratories has an enhanced importance now more than ever because science as a way of knowing is a cultural entity. That is, the claims of science and the methods of

science impact our lives in very direct ways, defining, challenging and redefining our perspectives about nature and the world. The National Science Education Standards recognize this through the inclusion of social perspectives about science and technology as distinct content standard. The game of science, not surprisingly, has become more nuanced as scientific inquiry becomes more focused on disciplinary specializations and increasingly takes on problems concerning the human condition like hunger, risk assessment, environmental quality, disease, energy, and information technology, among others. Our high school students and their parents do indeed have a perspective and partial understanding of scientific issues and frequently espouse alternative perspectives that challenge established scientific claims. The implication is that the role of the laboratory in high school science must adapt to being more than a mechanism for teaching what we know.

The emphasis on concept and process learning in science education has, in my opinion, contributed to an image of science education that emphasizes the confirmation role of laboratory work, as opposed to a model-based role of laboratory. In a confirmation lab, the concepts and processes are presented via lecture and/or text and then a demonstration and/or investigation is conducted to confirm how the evidence links to the conceptual understanding. In this way, science education becomes final form science (Duschl, 1990) or as Schwab warned a ‘rhetoric of conclusions’. What the 4 types of knowledge indicate is that a model of science learning and the goal of laboratory experiences must go well beyond the acquisition of declarative knowledge.

A strong implication from cognitive research on learning and teaching is that conceptual understanding, practical reasoning, and scientific investigating are three capabilities that are not mutually exclusive of one another. Thus, an educational program that partitions the teaching and learning of content from the teaching and learning of process, cognitive and manipulative, will be ineffective in helping students develop scientific reasoning skills and an understanding of science as a way of knowing.

Another development that affects thinking about the role of laboratories in science education is the learning science research on effective learning environments. Again, in very broad brushstrokes, the research suggests effective learning environments are ones that scaffold or support learning through the use of effective mediation or feedback strategies. Research on learning has demonstrated the importance of social, epistemic and cultural contexts for learning (Bruer, 1993; Brown & Campione 1994; Pea 1993; Goldman, et al, 2002; Sandoval & Morrison, 2003). One of the implications coming out of the research is the assessment of laboratory work in science education. Another conclusion coming out of such research is that language development for learning and reasoning is critical.

Assessing Science Lab²

A review of the science education assessment literature indicates that the compartmentalisation of scientific learning continues to be a dominant perspective even today as measured by the contents of standardised tests used for international and national assessments in the United States. The review of

² This section is derived from Gitomer and Duschl (1998).

research on assessment in science by Doran, Lawrenz and Helgeson (1994) shows that the traditional separation orientation is prominent. Their review of large scale international (IAE), national (NAEP) and state and provincial government assessments is a comprehensive listing of testing programs that rely on traditional distinctions and beliefs.

The history of science education has been to partition assessment of conceptual components of science from the process, practical, inquiry and attitudinal components of science. Even new assessment procedures, such as those developed in Connecticut and California, though modifying how students report and record their responses to assessment problems, still tend to evaluate in accordance with a process/conceptual dichotomy (Baron 1990; Shavelson, Baxter & Pine, 1992). Indeed, many of the tasks are adaptations of process skill activities developed by National Science Foundation sponsored curriculum projects from the 1960s.

Many recent efforts remain strongly influenced by the tradition of laboratory practical examinations. For instance, the Doran, Lawrenz & Helgeson (1994) discussion of performance assessment focuses exclusively on laboratory and inquiry skills. For many science educators, laboratory practical examinations are alternative assessments. Hence, it is not surprising that the perspective of performance-based assessments used in science today (Doran & Tamir 1992; Kanis, Doran & Jacobson 1990; Shavelson, Baxter, & Pine 1992) has a great deal in common with the practical examination formats promoted years ago (Hofstein & Lunetta 1982; Lunetta & Tamir 1979; Lunetta, Hofstein & Giddings 1981; Tamir 1985). As one example, the report on alternative assessment of high school laboratory skills by Doran, Boorman, Chan and Hejaily (1993) partitions skills as they relate to planning, carrying out and analysing data from investigations as well as applying results to new contexts.

Without a doubt, there is a shift away from partitioning and toward integrating curriculum, instruction and assessment. Millar and Driver (1987), for example, argue that the processes of science cannot be restricted only to those involved in investigations. Students' prior knowledge and the context in which an inquiry is set affect the ways in which students ultimately will engage in an investigation or laboratory exercise. Hodson (1993) echoes a similar concern by reminding science educators to consider the fact that all investigative, hands-on or practical approaches in classrooms occur within an epistemological context that affects students' understandings of the tasks. This position is similar to that made about the importance guiding conceptions have in the design, implementation and evaluation of scientific inquiries (Schwab 1962).

Thus, changes in social values have given rise to a new generation of assessment items and instruments (e.g., authentic tasks, performance-based task and dynamic assessments) and a set of new strategies and formats (e.g., portfolios). Champagne and Newell (1994) report that an expanded role of assessment in science ought to include considerations for three areas of performance capabilities: (1) conceptual understanding; (2) practical reasoning; and (3) scientific investigation. They offer some assistance toward understanding the ways in which assessments need to be expanded so as to take into

consideration the reasoning of learners. For them, the diverse role of performance assessments can be divided into three groups:

- 1) Academic performance assessments which include traditional laboratory practical exams and other closed-ended school problems;
- 2) Authentic tasks like BSCS's 'Invitations to Inquiry' which involve real-world, open ended tasks that involve students in question framing, experimental design, and data analysis;
- 3) Dynamic or developmental assessments given over the course of a year or several years which measures students' potential for change over time as determined by students' responses to feedback on a task.

Together, changing social values of the purpose of assessment and of the nature of school science have profound implications for science assessment and for the role of the laboratory in high school science assessment. Moving to performance assessments that emphasize the integration of conceptual understanding, reasoning and investigatory skill has important consequences for the role of high school labs in science education and for the kinds of inferences that are to be made, for the very construct that can be thought of as "science achievement" is being redefined (American Association for the Advancement of Science 1993; National Research Council 1996). This redefinition poses significant challenges to the making of claims about student ability that transcends a particular performance, in essence, the generalisability problem.

A second implication is that increased emphasis on the role of assessment in supporting instruction and educational reform forces greater attention to the consequences of assessment than has been usual. The validation of inferences is not only required about student achievement with respect to a defined domain and construct, but evidence is needed concerning the consequences of assessment practices for supporting instructional practices that lead to more successful learning for larger groups of students. This is, in assessment terminology, the consequential validity problem.

Language Development & Argumentation in Science Education³

Conceived as a sociocultural process, language development in science, in mathematics, in music, or in history involves development of the syntactical, semantic and pragmatic language structures of a domain. A critical aspect to the development of reasoning in a domain is the appropriation of language in that domain (Gee 1994; Lemke 1990). The implication of focusing on data texts (Ackerman, 1985) and model-based science in science education programs is that the language of science is extended beyond the purely linguistic. The language of science includes mathematical, stochastic, and epistemological elements as well. The challenge for learning science research is one of understanding how to mediate language acquisition in these various ways of communicating and representing scientific claims. Here again, immersion units designed to make thinking visible and to scaffold reasoning have been found to be

³ This section is derived from Duschl & Osborne (2002).

successful (Bell & Linn, 2000; Linn, 2000; Schauble, Glaser, Duschl, Schulze & John, 1996; Sandoval & Reiser, 2004).

A significant insight towards changing the role of laboratory that has developed over the last 50 years, and yet only partially realized at the level of the classroom, is the important role language plays in learning, and in the design of effective learning environments. For a prominent, if not central feature, of the language of scientific enquiry is debate and argumentation around competing theories, methodologies, evidence and aims. Such language activities are central to doing and learning science. Immersion units provide special opportunities to develop such language skills and to do so with respect to both conceptual and epistemic learning goals. Figure 1 presents a schematic representation of the evidence to explanation continuum and the dialectic opportunities for epistemic conversations across science lessons. Importantly, 4-6 week long full-inquiry units provide affordances to focus on the data texts of scientific inquiries. Thus, enabling an understanding of science and opportunities for appropriating the syntactic, semantic and pragmatic components of its language. The question with regard to the role of the laboratory in high school science is the extent to which students need to be engaged in the collection of data, the analysis of data or both.

The issue then is one of emphasis and educational aims with an eye toward engaging students in practicing and using scientific discourse in a range of structured activities. The role of the laboratory is important but a proper balance between times allocated to the collection of data and the skills of measurement and time allocated to data analysis and modeling needs to be struck. The role of the laboratory should NOT be to confirm conceptual frameworks presented in textbooks. At the high school level, the role of the laboratory should begin to take advantage of the skills, questions and interests students bring to the classroom. That is, if the structures that enable and support dialogical argumentation are absent from the classroom, it is hardly surprising that student learning is hindered or curtailed. Or, put simply, teaching science as a process of inquiry without the opportunity to engage in argumentation, the construction of explanations and the evaluation of evidence is to fail to represent a core component of the nature of science or to establish a site for developing student understanding. Herein lies the importance of immersion units situated in design, problem, and project contexts.

Teaching science as an enquiry into enquiry must address *epistemic goals* that focus on *how we know* what we know, and *why we believe* the beliefs of science to be superior or more fruitful than competing viewpoints. Osborne (2001) has argued, if science and scientists are epistemically privileged, then it is a major shortcoming of our educational programs that we offer so little to justify the accord that the scientists would wish us to render unto scientific knowledge. Hence, if the rationale for universal science education lies in its cultural pervasiveness and significance, then attention must be given to explaining why science is considered the epitome of rationality, and why scientific thinking is the dominant paradigm of contemporary society. In short, the challenge is exposing the nature of science and the values that underlie it. The role of the laboratory is vital in meeting this challenge because the authority of science lies within the evidence and within the reasoning linking evidence to explanation.

From such a perspective, one critically important task is establishing or engineering a context in which epistemic dialogue and epistemic activities can occur (De Vries et al., 2002). Fundamentally this requires creating the conditions in which students can engage in argumentation; i.e., to explore critically the coordination of evidence and theory that support or refute an explanatory conclusion, model or prediction (Suppe, 1998). Situating argumentation as a critical element in the design of science laboratory learning environments both engages learners with conceptual and epistemic goals and, for the purposes of the practice of formative assessment by teachers, can help make scientific thinking and reasoning visible. Central to a view of the value of argumentation is a conception, proposed by Ohlsson (1995), of discourse as a *medium*, which stimulates the *process* of reflection through which students may acquire conceptual understanding. For as De Vries et al, states discourse activities are important because:

In comparison with problem solving activities, they embody a much smaller gap between performance and competence. In other words, the occurrence of explanatory and argumentative discourse (performance) about concepts effectively reveals the degree of understanding of those concepts. Epistemic activities are therefore discursive activities (e.g. text writing, verbal interaction, or presentation) that operate *primarily on knowledge and understanding*⁴, rather than on procedures.

The view, then, is that epistemic goals are not to be seen as additional extraneous aspects of science that are marginalized to single lessons or the periphery of the curriculum (Duschl, 2000). Rather, striving for epistemic goals such as the ability to construct, evaluate and revise scientific arguments offers a means of attaining cognitive aims *as well*. Yet, as Newton, Driver and Osborne (1999) have shown, opportunities for such deliberative dialogue with science classrooms are minimal. Thus, a renewed image of the role of laboratory in high school science ought to embrace and then include in instruction the dialectical processes that engage learners in linking evidence to explanation, i.e., argumentation.

Argumentation has three generally recognized forms: analytical, dialectical, and rhetorical (van Eemeren et al, 1996). The application of analytical arguments (e.g., formal logic) to evaluate science claims is extensive and pervasive. The capstone event of applying argumentation to the sciences is perhaps Hemple-Opppenheimer's Deductive-Nomological Explanation Model (Hemple, 1965) wherein the argumentation form is used as an account to establish the objectivity of scientific explanations. Toulmin's (1958) examination of argumentation was one of the first to challenge the 'truth'-seeking seeking role of argument and instead push us to consider the rhetorical elements of argumentation. For Toulmin, arguments are field dependent. As, in practice, the warrants and backings used to make claims are shaped by the guiding conceptions and values of the field. For in science, what counts as evidence, and the theoretical assumptions driving the interpretations of that evidence, are consensually and socially agreed by

⁴ Emphasis added

the community – an idea recognized by Schwab who saw the teaching of science as an investigation of the guiding conceptions that shape enquiry.

Likewise, case studies of scientists engaging in scientific enquiry show that the discourse of science-in-the-making involves a great deal of dialectical argumentation strategies (Dunbar, 1995; Latour & Woolgar, 1979; Longino, 2002; Gross, 1996). Research in the sociology of science (Collins & Pinch, 1994; Taylor 1996) has also demonstrated the importance of rhetorical devices in arguing for or against the public acceptance of scientific discoveries. In short, the practice of science consists of a complex interaction between theory, data and evidence. The rationality of science is founded on the ability to construct persuasive and convincing arguments that relate explanatory theories to observational data. Thus science requires the consideration of differing theoretical explanations for a given phenomena, deliberation about methods for conducting experiments, and the evaluation of interpretations of data. Clearly then, argumentation, as science education research has shown, is a genre of discourse central to doing science (Lemke, 1990; Kuhn, 1993; Siegel, 1995; Kelly & Crawford, 1997; Kelly, Chen & Crawford, 1998; Suppe, 1998; Newton, Driver and Osborne, 1999; Driver, Newton, & Osborne, 2000; Loh, et al, 2001). And, if students are to be persuaded of the validity and rationality of the scientific world-view then the grounds for belief must be presented and explored in the context of the science classroom. In short:

‘the claim ‘to know’ science is a statement that one knows not only *what* a phenomenon is, but also *how* it relates to other events, *why* it is important and *how*⁵ this particular view of the world came to be. Knowing any of these aspects in isolation misses the point.’ (Driver, Newton and Osborne: 2000)

Such an aim requires the opportunity to consider *plural* theoretical accounts and the opportunity to construct and evaluate arguments relating ideas and their evidence. For as Kuhn (1993) argues, ‘only by considering alternatives – by seeking to identify what is not – can one begin to achieve any certainty about what is.’ Not to do so will leave the student reliant on the authority of the teacher as the epistemic basis of belief leaving the dependence on evidence and argument – a central feature of science – veiled from inspection. Or, in the words of Gaston Bachelard (1940), the essential function of argument is that, ‘two people must first contradict each other if they really wish to understand each other. Truth is the child of argument, not of fond affinity.’ Indeed, Ogborn et al. (1996) show elegantly how one of the fundamental strategies of all science teachers is the creation of difference between their view and their students’ view of phenomena. For without difference, there can be no argument, and without argument, there can be no explanation. Within the context of science, dedicated as it is to achieving consensus, it is argument, then, that is a core discursive strategy, and a *sine qua non* for the introduction of argument is the establishment of differing (i.e. plural) theoretical accounts of the world. This is not to suggest that argument is something, which is unique to science. Argument plays a similar function in many other disciplines. Rather, the intent

⁵ Emphasis in the original

is to show that *argument is as central to science as it is to other forms of knowledge* and, therefore, cannot be ignored in any science education.

Mitchell (1996) is helpful in this matter by distinguishing between two types of argument - regular and critical arguments. Regular arguments, she states, are rule-applying arguments that put forward applications of theories that are not in themselves being challenged. Such arguments are generally predictive and a central feature of the work of scientists. In contrast, critical arguments do challenge the theories and ideas but have as a fundamental goal the refinement of existing theories or introduction of alternative ideas and not the defeat of another. In the moral community that is science, personal conflicts and aspirations are always secondary to the advancement of knowledge.

We must remember, therefore, that initial efforts with engaging children in argumentation will require setting ground rules to avoid, for instance, ad hominem arguments that attack the person and not the ideas (Dillon, 1994). Such preliminary attempts to initiate argumentation practices will also require modeling and practicing the standard inductive (argument by example, argument by analogy, argument by causal correlation) and deductive (argument from causal generalization, argument from sign, syllogisms) forms of argument. Worth mentioning at this point is the research (Duschl, Ellenbogen & Erduran, 1999) that shows children do seem to have a natural tendency to engage in such inductive and deductive forms of argument when a sound context is provided.

Thus, like Cohen (1994) seeing argumentation as war is an ineffective and inappropriate metaphor for promoting dialogic discourse – a metaphor that must be explicitly refuted and countered when initiating the contexts for argument in the classroom. The alternative is to envision argumentation as a process that *further*s inquiry and not as a process that ends inquiry. Thus, alternative and more apposite metaphors for Cohen (1995) include argumentation as diplomatic negotiation, argumentation as growth or adaptation, metamorphosis, brainstorming, barn raising, mental exercises for the intellect or roundabouts on the streets of discourse. Science as a way of knowing does seek consensus on matters but, more often than not, progression in scientific thinking involves the use of critical arguments and processes that are more akin to diplomatic negotiation than to conflict. In this way, lab based science can be a dialogic process.

Harvey Siegel (1995) in an article titled “Why should educators care about argumentation?” takes the position that if one ideal of education is the development of students’ rationality, then we must be concerned not only with how students reason and present their arguments but also with what students come to consider as criteria for good reasons. Siegel sees argumentation as the way forward because of the correlation between the ideal of rationality and the normative concerns and dimensions of argumentation and argumentation theory. He writes, “Argumentation . . . is aimed at the *rational* resolution of questions, issues, and disputes. When we engage in argumentation, we do not seek simply to resolve disagreements or outstanding questions in any old way Argumentation . . . is concerned with/dependent upon the *goodness*, the *normative status*, or *epistemic forcefulness*, of candidate reasoning for belief, judgment, and action.” (p 162, emphasis in original). Thus the second concern with the introduction of argumentation is the necessity to model effective arguments in science, to expose the criteria which are used for judgment

such as parsimony, comprehensiveness and coherence, and why some arguments are considered better than another. For instance, given two arguments to explain the 24-hour rotation of the Sun and stars why do we pick the argument that it is the Earth that is moving rather than the Sun and stars.

Critically important to argument is allowing learners to have the time to understand the central concepts and underlying principles (e.g. the “facts”) important to the particular domain (Goldman, et al, 2002). In other words, a necessary condition for good arguments is a knowledge of the “facts” of a field as otherwise there is no evidence which forms the foundation of a scientific argument. Alternatively, students must be provided with a body of ‘facts’ as a resource with which to argue (Osborne, Simon and Erduran, 1999). However, argumentation does not necessarily follow from merely knowing the “facts” of a field. Equally important is an understanding of how to deploy the “facts” to propose convincing and sound arguments relating evidence and explanation. Herein lies the need for learners to develop strategic and procedural knowledge skills that underpin the construction of argument. Herein lies the need for the laboratory to be situated into immersion units in high school science programs.

In summary, the challenge is providing teachers and students with tools that help them build on nascent forms of student argumentation to develop more sophisticated forms of scientific discourse (Duschl et al, 1999; Osborne, Erduran, Simon, & Monk, 2001). Such tools need to address the construction, coordination, *and* evaluation of scientific knowledge claims. Equally important, as Siegel (1995) argues, is the need to address the development of criteria that students can employ to determine the goodness, the normative status, or epistemic forcefulness of reasons for belief, judgment, and action. What has been presented is that the central role of argumentation in doing science is supported by both psychologists (Kuhn, 1993) and philosophers of science (Siegel, 1995; Suppe, 1998) as well as science education researchers studying the discourse patterns of reasoning in science contexts (Sandoval & Reiser, 2004; Bell & Linn, 2000; Driver, Newton & Osborne, 2000; Hogan, Nastasi & Pressley, 2000; Kelly, Chen, & Crawford, 1998; Kelly & Crawford, 1997; Lemke, 1990). Designing learning environments to both facilitate and promote students’ argumentation is, however, a complex problem. For the central project of the science teacher is to persuade his or her students of the validity of the scientific world-view. Conceived of in this manner – as a rhetorical project – the consideration of plural enterprises simply undermines the science teacher’s task and threatens the learner’s knowledge of ‘the right answer’. Moreover, normal classroom discourse is predominantly monologic and it is difficult for teachers to transcend such normal modes of discourse. Therefore, changing the pattern and nature of classroom discourse requires a change both in the structure of classroom activities and the aims that underlie them. Laboratory style investigations embedded in immersion units are the way forward.

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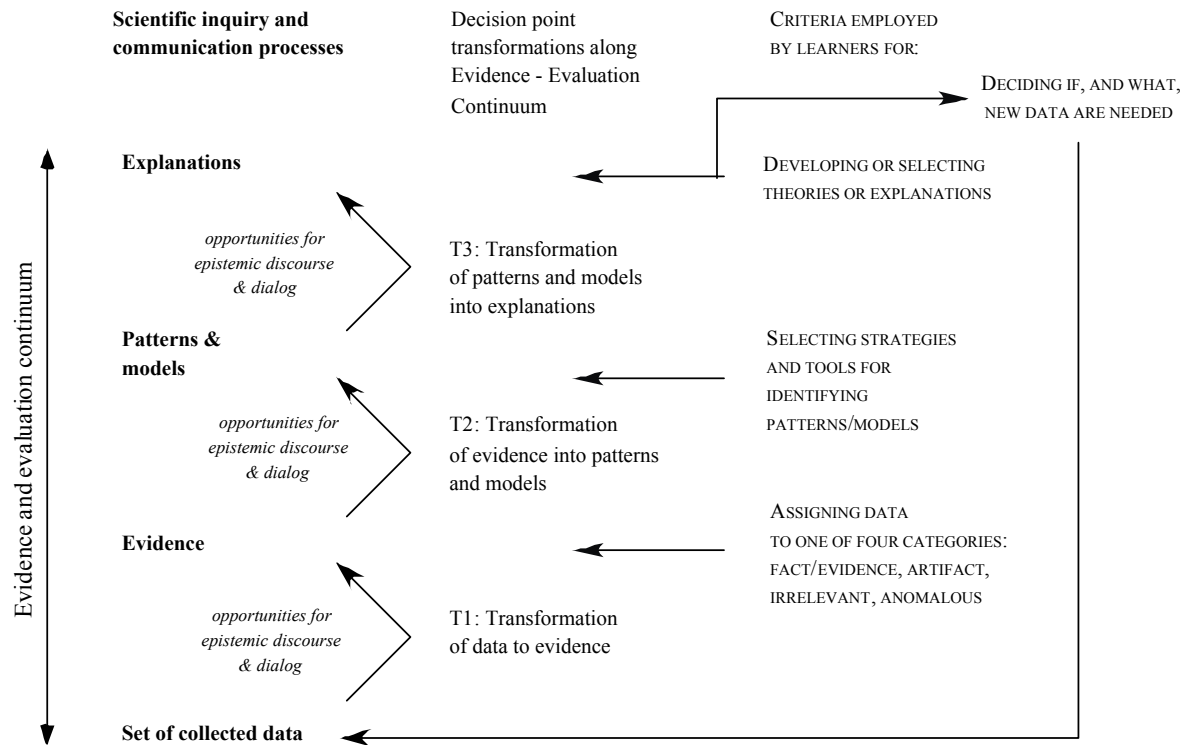


Figure 1. Schematic of Evidence-Evaluation continuum model for consideration of epistemic dialog opportunities