A Science and Technology Studies Lens for Studying Teacher Practice

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Over the last decade, the field of Science and Technology Studies (S&TS) has gained increased interest amongst science educators and science education researchers. Such work has primarily focused in two veins. S&TS has been used to define new areas of content, generally referred to as the Nature of Science (NOS). This has included research into students' understanding of NOS, teachers' understanding of NOS, and inclusion (or exclusion) of NOS themes in curricula. A second vein of inquiry has been the investigation of the classroom as a microcosm of scientific discourse and inquiry. Such research has included investigations of student-to-student and student-to-teacher interaction. In this paper, we aim to present our efforts to extend use of S&TS to a third vein – the investigation of teacher knowledge and practice.

We find the perspective of S&TS, particularly its sociological basis, useful for investigating teacher knowledge and practice. As such, we conceptualize curricula as technologies, and teacher practice as a sociologically constructed phenomenon and recognize the contextual nature of knowledge. In this paper, we aim to develop a "sense of place" (Mueller 2001) in the S&TS literature, in order to provide a better orientation to the context of this field and its applications to education. Thus, we spend a significant bit of time up front describing this literature base in order to ground our work in this setting.

We begin with a broad overview of the history of S&TS to set the context for describing its sociological perspective. We then focus on several key themes within S&TS we find useful to the educational arena. This discussion includes specific examples from the S&TS literature and suggested parallels in educational practice. We end by providing excerpts from two ongoing studies as exemplars of implementing the S&TS methodologies in teacher practice.

Overview of S&TS

We first provide an overview of the development of the S&TS field, focusing on the main branches of the Sociology of Scientific Knowledge (SSK) and the Social Construction of Technology (SCOT).

Sociology of Scientific Knowledge

The sociology of scientific knowledge describes the practices of science, the construction of scientific fact, and the interactions between science and society. Central to many sociological studies of science has been the role that the community of scientists plays in the creation of scientific knowledge. Unlike the image often propagated by school science, scientific knowledge cannot be created by an individual in isolation; to become accepted as scientific "fact" a claim (and the research supporting it) must be reviewed and critiqued by one's scientific colleagues. Data does not speak for itself—a scientific community must pass judgment, accept the findings, and then reinforce them through use in subsequent studies.

In the 1970s, sociologists of science, seeking to describe the culture of science, began to study the practice of science at the laboratory bench. In particular, they investigated the interrelationship between the scientific method (or, more accurately, the actual practice of science) and scientific knowledge—they wanted to understand how scientific statements evolve from scientific practice (Latour and Woolgar 1986; Traweek 1988; Sapp 1990; Mueller 2001).

Sociological "laboratory studies" have helped redefine the fundamental purposes and activities of empirical work, and the relationship between scientific writing and research. Most lay people believe that scientists do research and then report their results. They notice or observe facts, test them, and then disseminate their findings through writing; an image often promoted by scientists themselves (Latour and Woolgar 1986; Sapp 1990). Writing, dissemination, and

acceptance of results are seen as separate from, and secondary to, research activities (Gough 1992). But laboratory studies, particularly Latour and Woolgar's (1986), demonstrate the interdependence of writing, research, and the production of knowledge. In reality, the scientific laboratory does not function as a link between a problem and a solution (Cozzens 1990), but rather as an instrument of persuasion (Latour and Woolgar 1986) or a "fact factory" (Knorr-Cetina 1995). Researchers focus their energies on persuading themselves and others that what they have perceived is important and that their interpretations are valid.

Ethnographers, struck by the "seething confusion" that characterizes scientific laboratories, describe the construction of scientific facts as a long, gradual process of working to create order from the disorder (Latour and Woolgar 1986; Lynch 1988; Sapp 1990). To make assertions, scientists must try to distill messy data from background noise. Their initial tentative written claims serve to initiate a conversation with other scientists (Hull 1988). Decontextualization and successive removal of uncertainty accompany the rise in status of a claim; "weasel words" (Hull 1988), modalities (qualifiers suggesting uncertainty or contingency), and any references to social, historical, or personal contexts (Latour and Woolgar 1986) slowly disappear; rhetorical, visual, and organizational aids are added to make the data "clearer" (Lynch 1988).

Collins and colleagues have developed the Empirical Programme of Relativism (EPOR) as a means to operationalize the study of the social construction of science. The first stage of EPOR involves illustrating the *interpretive flexibility* of observations. Interpretive flexibility refers the possibility of multiple explanations for empirical data. In essence, this is a requirement to produce the sociological empirical evidence to the underdetermination of scientific fact.

> All the papers [in this set] confirm the potential local interpretive flexibility of science which prevents experimentation, by itself, from being decisive. In particular, the socially-negotiated character of experimental replication is further documented. (Collins 1981, p. 4)

This multiplicity of possibility generally does not last, however. Social negotiation generally provides closure on the issue. The second stage of EPOR is to describe and explain the mechanisms that provided this closure. EPOR has a third stage, which is yet to be carried out for contemporary science. This is to connect the findings of the first two stages to the greater societal structure.

For Longino, "objectivity of scientific inquiry is a consequence of this inquiry's being a *social* [emphasis added] and not an individual enterprise" (Longino 1990, p. 67). She claims,

> It is important to distinguish between objectivity as characteristic of scientific method and objectivity as characteristic of individual scientific practitioners or of their attitudes and practices. The standard accounts of scientific method tend to conflate the two, resulting in highly individualistic accounts of knowledge. (Longino 1990, p. 66)

Longino takes issue with "individualistic accounts of knowledge;" although an individual can surface plausible claims in the context of discovery, she cannot produce knowledge (Longino 1989). Sociologists have described how the production of scientific knowledge requires judgment and acceptance by the larger scientific community. Longino retains the focus on community, not individuals, as the agents of knowledge: "Because community values and assumptions determine whether a given bit of reasoning will pass or survive criticism and thus be acceptable, individual values as such will only rarely be at issue in these analyses" (Longino 1990, 82).

Social Construction of Technology

Over a decade ago, using understandings from the Sociology of Scientific Knowledge (SSK), Pinch and Bijker (1987) developed a model for the Social Construction of Technology (SCOT). They now use SCOT to analyze socially significant groups, the users of various technological artifacts, as agents of technological change (Pinch and Bijker 1987).

Distinctly opposite to the common interest in the ways technology affects society, SCOT looks at the evolution of technology and highlights the role relevant social groups play in the negotiation of technology's structure and function. This genealogy often reveals alternative possibilities to what had become the standard design of a technology. Determination of the prevailing design is a product of the interaction of different relevant social groups. Both in the technology design phase and after assumed closure (stabilization of an artifact), users' interactions with technological artifacts can effectively result in their reconfiguring the technology (Pinch and Bijker 1987; Kline and Pinch 1996).

Based on the EPOR model described above, in SCOT, technology as a developmental process is described as an alternation of variation and selection, which results in a multidirectional model of analysis. A major tenet of this model claims that the design, technical content, and use of technological artifacts are all open to sociological analysis. It incorporates three components for examination in user analyses: the role of relevant social groups and interpretive flexibility of an artifact, closure or artifact stabilization, and a detailed description of the case studies of users and their technologies for communication to the larger context.

Relevant social groups are defined as groups of individuals who share an artifact's meaning (Kline and Pinch 1996). Different groups can have different meanings for the same artifact, reflecting an instance of interpretive flexibility. Because technology is considered culturally constructed and interpreted, not only is there flexibility in how people think of or interpret artifacts, but there is also flexibility in how artifacts are defined or stabilized. This opportunity for interpretation lends itself to many different paths of artifact construction by the various relevant social groups. These paths are examined to gain insight into the multiple ways that a technology can be shaped and reshaped during its life cycle. This process usually continues until

closure or the stabilization of the artifact occurs, meaning one form of the artifact has become

more dominant over other forms. Alternatively, closure is said to occur when the relevant social

group no longer perceives problems surrounding the artifact or a solution to problems has been

determined. Closure can also occur if the problem has been redefined as such, that the artifact

now becomes the solution. Closure may not necessarily result in the disappearance of all

alternative forms of the technology, however—several forms can exist simultaneously.

Additionally, closure can be temporary—new problems can emerge which once again result in a

resurgence of interpretative flexibility leading to the re-stabilization of the artifact. In an attempt

to examine the larger context, SCOT offers rich case descriptions of the social groups'

interactions with the technology. This is a means of examining the ways in which groups shape,

interpret, and change the design of artifacts once considered to be fairly stable.

Bijker (1987) further extends the importance of different perspective amongst groups through

the concept of a technological frame. This is intended to be a broad concept, including the

concepts and techniques used by a social group in solving a problem - recognizing that problem

solving includes recognition of what the problem is – and is somewhat analogous to Kuhn's

(1970) paradigm (Bijker 1987). The technological frame plays a crucial role in determining a

social group's perspective on technology formation:

> [T]he meanings attributed to an artifact by members of a social group play a crucial role in my description of technological development. The technological frame of that social group structures this attribution of meaning by providing, as it were, a grammar for it. This grammar is used in the interactions of members of that social group, thus resulting in a *shared* meaning attribution … The interactional nature of this concept is needed to account for the emergence and disappearance of technological frames. (Bijker 1987, 172)

Bijker thus intends for the technological frame to be not a characteristic of individuals, but a

mediation for the interaction between actors. He also points out that it is involved in how social

conditions shape technological solutions and how technical solutions shape social conditions.

Earlier studies in technological development examined the influence of <u>innovators</u> (designers, manufacturers) on the form and design of technological artifacts (Callon 1987; Law 1987; Bardini and Hovarth 1995). A number of studies centered on these technological innovators as the major controllers of technological systems and artifacts (Callon 1987; Law 1987; Woolgar 1991; Bardini and Hovarth 1995). These investigations focused on the innovators' influence on the design phase of technology. Investigators found that innovators tended to construct the artifacts in their own image. Consequently, the technology they created limited, in fact, the end-user (Woolgar 1991; Bardini and Hovarth 1995). Thus, according to Woolgar (1991), both the form of the artifact and the intention of the innovator (direct or indirect) have limited users' access to and knowledge of the "machine (technology)." As a result of this co-construction, the technology creates a boundary between the innovator (insider) and the user (outsider). On the other hand, in her studies on users and technologies, Lindsey (1999; 2000) disagrees with Woolgar's boundary separation. She argues that users may fall into many different categories and that Woolgar's distinction between only the two categories of insiders and outsiders is insufficient.

Increasingly there has been a shift of focus in SCOT studies from the innovators to the users. Following the technology into the hands of the user has provided a ripe area of investigation. As at least one researcher has found, once the technology gets into the hands of the actual users, this boundary becomes less clear and in some instances, actually dissolves or is reworked (Lindsay 1999). In her research, Lindsey (2000) followed a specific technology throughout its life cycle and observed:

> [Users and technology are presented] as a combined element. People only become users when they come into contact, in some way, with a particular technology. A social constructivist perspective introduces interpretive flexibility, the idea that the use and meaning of a technology may be interpreted in different ways by different groups of people. This leads to recognition that the relationships between users and technology are fluid and continually negotiated. Users often

> do unanticipated things with a technology, and the technology may have a different role in a person's life than for which it was designed. (Lindsey 2000, p. 4)

"Users" are described as mythical or virtual figures for whom a technology is designed (Lindsay 1999); they are often thought of as being configured or scripted by the inventors of the technology (Woolgar 1991; Akrich 1992). Past practice indicates that innovators design technologies under the assumption that the technology's final form is—and will be—uncontested by the end-user. However, studies that unearth the developmental stages of a technology *and follow it through its implementation* phase show that users are <u>not</u> passive. They are capable of interacting with technologies in ways the designers may not have predicted. In fact, users often reconfigure the "finished product". By opening and examining an artifact or technology, unforeseen or unintended consequences surrounding the artifacts' uses can be explored.

<center>Themes</center>

We now move from a general overview to five specific themes, and their possible manifestation in education. In doing so, we expand the obvious bounds of S&TS. S&TS has always studied scientists as professional practitioners, and key entities in the creation of knowledge. Thus, we conceptualize teachers as professional practitioners, and actors in a particular instance of knowledge creation. Likewise we view curricula as technologies, continuing the practice of a broad conception of technology (Shapin and Shaffer 1985; Bijker 1987; Mulcahy 1998):

> By using technology to refer to literary and social practices, as well as to machines, we wish to stress that all three are knowledge-producing tools (Shapin and Shaffer 1985, p. 24)

> That 'technology' comprises more than machines... 'Technology' can include social arrangements as diverse as the postal system, transportation, refuse collection, voting mechanisms, education, and so on. (Woolgar 1991, p. 94)

Teachers are viewed as "users" of those technologies (Bardini and Hovarth 1995; Kline and Pinch 1996; Mulcahy 1998; Lindsay 1999). As technological users, teachers act as agents of technological change (Pinch and Bijker 1987; Kline and Pinch 1996).

Social Construction

As indicated in the discussion so far, possibly the most central theme in S&TS is the socially constructed nature of science. In particular, the Strong Programme within sociology of scientific knowledge was created explicitly to explore the importance of social negotiation in the production of facts. It has posited that both true and false beliefs should require sociological explanation. Central to the justification for this approach is the stance that empirical evidence alone underdetermines scientific knowledge. Social construction is necessary to move empirical data to established fact. One misunderstanding of this approach is to view it as an overly relativistic attack on scientific integrity. Rather, it is an endeavor to examine the role the social plays in that integrity. "The feeling that there is some truth to which a calculation corresponds is not rejected…[that truth is relocated] in utility and the enduring character of social practice" (Bloor 1973, p. 188).

Thus the solution to underdetermination lies not with Nature or with the individual, but with others. This is the essence of Latour's *First Principle*:

> The fate of facts and machines is in later users' hands; their qualities are thus a consequence, not a cause of a collective action. (Latour 1987, p. 259)

Latour uses the two headed Janus to illustrate many instances where this social constructionist view has the effect of reversing conventional wisdom.

> 'Of course,' says the left side of Janus, 'everyone is convinced because Jim and Francis stumbled on the right structure. The DNA shape itself is enough to rally everyone.' 'No, says the right side, every time someone else is convinced it progressively becomes a more right structure.' (Latour 1987, p. 13)

Another consequence of this principle is that meaning comes from use. The meaning of the helical structure of DNA comes not from its definition, but from the utility others have found in it.

Now let us turn to education. The basis for the sociological study of science is the underdetermination of scientific fact by empirical evidence – hence the need for a social process.

Can a similar argument be made? Certainly when considering the institution of education as a whole, it takes little effort to argue for a sociological element, and the suggestion is almost trivial. However, we want to narrow the focus on a much less obvious area – school science and teachers' knowledge and practice in carrying out that school science. Here there is a far more interesting and significant parallel argument. Just as scientific facts are underdetermined by empirical evidence, school science is, in turn, underdetermined by scientific facts. In other words, there is still work to be done in determining the nature of a scientific concept as part of school science (and therefore teacher knowledge and practice) after work has been done in creating it as part of scientific knowledge. (This is, after all, much of the reason for the use of the term "school science".) There is as much of a contextuality to the content of school science as there is to general scientific knowledge.

Consider, for example, the gas laws. At this time, there is likely to be little or no dispute amongst scientists about this scientific knowledge. But does this mean that the manifestation of gas laws in high school is unproblematic? Examining textbooks – presumably accurate representations of scientific knowledge - begins to reveal that it is. Comparing two particular high school chemistry textbooks, each contains a section labeled "gas laws" (as do, in fact, most high school chemistry textbooks) in which they each give a treatment of this topic. Textbook A presents "Boyle's Law" and "Charles' Law", and then uses them to present the "Combined Gas Law" (Choppin and Simmerlin 1982, p. 96):

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Textbook B presents "Boyle's Law" and "Charles' Law" as well, but also presents "Avogadro's Law", and combines the three into the "ideal-gas equation" (Brown and Lemay 1988, p. 309):

$$PV = nRT$$

It then goes on to use this equation to present the "Combined Gas Laws". The two treatments are not identical. On the other hand, they are quite similar, especially compared to an advanced statistical mechanics textbook. This textbook contains no section labeled "gas laws". One will find:

$$\bar{p}V = \boldsymbol{n}RT \quad \text{(Reif 1965, p. 125, Equation 3·12·10)}$$

but also

$$p = nkT \quad \text{(Reif 1965, p. 125, Equation 3·12·9)}$$

and even

$$\bar{p} = \frac{1}{\boldsymbol{b}}\frac{\P \ln Z}{\P V} \quad \text{(Reif 1965, p. 214, Equation 6·5·12)}$$

So the certainty of the scientific knowledge in the greater society was not sufficient to determine unambiguously the representation of that knowledge in the high school science class. The determination of school science is often problematic for the same reason the determination of scientific knowledge is often problematic – an excess of possibility.[i]

Clearly there are reasons for the high school chemistry textbooks to not be identical to the college statistical mechanics textbook. Work in teacher knowledge has actually well established this distinction between the formation and manifestation of scientific knowledge, and the formation and manifestation of school science. Teacher knowledge, more specifically pedagogical content knowledge (PCK), is often viewed with the perspective of its role in transforming general knowledge into knowledge for student conception (Shulman 1986; Shulman 1987; Wilson, Shulman et al. 1987; Grossman, Wilson et al. 1989; Van Driel, Verloop et al. 1998). However, this work has largely considered the question a matter of a teacher's individual cognition. That the transformational process is not trivial, and open to investigation, justifies investigation from a sociological point of view. Manifestations of school science certainly do not depend solely on scientific knowledge, and the addition of individual teacher

psychology may not be adequate.[ii] As an instance of knowledge, it deserves sociological

attention. Furthermore, investigating why the textbooks differ (and are similar) from a

sociological perspective offers another entry point into investigating teacher knowledge.

Social Interaction

As a sociological perspective, S&TS pays attention to the outward actions of actors, rather

than their inner world. As indicated in the discussion so far, this has meant a focus on the

objects that mediate interactions, and the relationships between actors. Latour and Woolgar

(1986) push the use of "inscriptions" to an extreme by characterizing the laboratory as a paper

producing factory. This allows them to trace the social interaction amongst actors and artifacts

without undo assumptions or reliance on scientists' interpretations. Latour (1987) also focuses

on literature as both the main means of interaction in the agonistic process, and a frequent asset

in establishing claims. This focus also reflects a general recognition of the overwhelming

presence of inscriptions and artifacts in scientific life.

The focus on artifacts should not be taken, however, as a behavioristic perspective.

> [I]t is worth recalling that "practical reasoning" is intended as a generic term for a variety of social processes whereby practitioners effect connections between what are taken as "surface documents" (which might take the form of signs, marks, indicators, utterances, actions, gestures and so on) and the "underlying reality" (which might include, for example, "what the mark shows", "what motivated that action", "what gave rise to this utterance", "the circumstances which render that gesture sensible" and so on). (Woolgar 1990, p. 123)

The intention, therefore, is to investigate the actions of actors, including products of those

actions, as social manifestations of meaning. In the introduction to a collection of work on

representation (Lynch and Woolgar 1990), Lynch and Woolgar (1990) argue for the legitimacy

of a bricolage approach to studying science. The key is focus on the actors *and* the objects.

> A line traced by an instrument on a chart recording, can be read in a variety of ways: its features can be treated as evidence of any number of worldly events, or of malfunctioning in the complex of instruments. How the display is read depends upon scientists' efforts to insert the document into the complex socio-technical relevancies of day-to-day investigation: who assembled the equipment, how it worked the last time it was used, what sorts of things have gone wrong or could

> go wrong with the apparatus, what sorts of proximal and distal events can the recording
> instruments "pick up," etc. (Lynch and Woolgar 1990, p. 10)

One extreme approach to this it to label everything "actors". This is the strategy used by Callon (1986) in investigating the politics of scallop research and fishing. The key distinction is the focus on outward acts rather than inward psychology. Documents, utterances, devices, procedures, and relationships and meaning given to them by actors are the substance of such an approach.

Like scientific life, school life is filled with inscriptions and artifacts. But, also like science, it is not only their mere presence that necessitates their study. Inscriptions and artifacts are the means by which knowledge is social, by which actors interact, and by which meaning is defined. Teacher knowledge, in following the general tendency in education, has been studied from a individual, psychological orientation. Studies in teacher knowledge may use devices such as a card sort or concept map exercise to evaluate teacher knowledge (cf. Carlsen 1991; Gess-Newsome and Lederman 1993; Van Driel, Verloop et al. 1998). What we are suggesting is the treatment of *knowledge as a social entity.* This is not just the implication that one teacher's knowledge is related to another's. It means the *study* of the knowledge from a sociological perspective. Knowledge is not just something located in the minds of individuals but also in myriad of devices through which subjects interact. This necessitates an approach akin to S&TS of focusing on inscriptions and artifacts, and actors' relationships with them. Thus what is important is not a teacher's ability to sort topics, but how knowledge is embodied in, for example, a test they use. One of the fallacies in the cognitive approach is the assumption that an individual's ability is the only factor in their practice. Consider an extreme case: If a Nobel Prize winning scientist teaches the gas laws by reading Textbook A, should our primary concern be

with the scientist's individual cognition of the subject matter? Or, should it be with the circumstances that explain the use of the textbook in the teaching of the class?

The methodological tools of S&TS highlight the processes and social influences that effect how and why teachers portray science in its social context. They allow for thick descriptions of actors and their social interactions with other actors or objects. For example, one can examine the interaction between the science teacher and an object such as a state -mandated test. In this instance, the focus becomes the negotiation between the teacher and the test including the language and use or reference to the test in the context of this teacher's science. Thus, the black box (see below)—the state test—can be opened for the sociological analysis of its' design, content, and use (Bijker 1987). Using these tools forces the researcher not to "privilege" (Bijker 1987) the teacher but allows for equal observational treatment of all human and nonhuman entities. It allows the researcher to explore taken-for-granted notions, such as the state test, without taking it for granted themselves.

<div align="center">Interpretive Flexibility</div>

The EPOR/SCOT cycle of interpretive flexibility/closure provides a central encapsulation of S&TS's key perspectives. It begins with the relativistic stance that provides the entry point for sociological investigation - namely that different actors or social groups can form different interpretations of evidence or technological problems and that knowledge must be situated in order to have meaning. Latour and Woolgar thus describe scientists as having to create knowledge from chaos and noise.

> [W]e argue that both scientists and observers are routinely confronted by a seething mass of alternative interpretations. Despite participants' well-ordered reconstructions and rationalisations, actual scientific practice entails the confrontation and negotiation of utter confusion. The solution adopted by scientists is the imposition of various frameworks by which the extent of background noise can be reduced and against which an apparently coherent signal can be presented. The process whereby such frameworks are constructed and imposed is the subject of our study. (Latour and Woolgar 1986, 36-7)

Latour and Woolgar term what follows this initial variation as an agonistic process. The EPOR/SCOT framework directs researchers to identify both instances of interpretive flexibility and means of closure.

More than a simple restatement of principles, therefore, the EPOR/SCOT frame work provides a methodological guide. So, for example, in following the case of the rural automobile, researchers would begin by looking for instances of interpretive flexibility (Kline and Pinch 1996). In this case, although the designers had a major influence on the form of the artifact, the artifact was reinterpreted and changed upon reaching the users. Several groups of users emerged following the introduction of the automobile, each having their own interpretation of the artifact. They include the urban car users, the anti-car group, and the rural farm users (male and female). Transportation – the designers' originally intended use – appealed to the urban car user. The anti-car group reacted strongly against the presence of the car on rural roads claiming it was a danger to farm animals, buggies, and pedestrians. They also claimed it caused damage to the local roads and referred to the car as the "devil wagon." This group went so far as to set traps for the cars and damage the roads making them dangerous or impassable to car drivers. They were also known to hurl objects or even shoot at the cars as they drove by. Had this group been successful, the car as we know it today may have only been used for short distance urban travel.

The rural users, on the other hand, developed a variety of uses for the car ranging from transport to reconfiguring it for various farm operations. For example, the farm men would jack up the rear axle, attach a belt to it and use the car as a stationary power source for certain farm equipment and even for domestic technologies such as the washing machine. Essentially, the rural farm users brought interpretive flexibility to the level of "reconfiguring the car" (Kline and Pinch 1996). The farmwomen also used the car both in its original form for transportation, and in

its reconfigured form for chores like running the aforementioned washing machine. These uses appear to have had a minimal impact on the women's domain of work on the farm.

As new designs hit the market for different user needs, such as Ford's release of the tractor and different truck version, closure began to occur. At this point, Ford began to publicly discourage both the alternative uses for the cars as well as the selling of kits (which were used by farmers to readily convert their autos into machines to generate farm equipment and chores), informing dealers that the warranties for cars sold with kits would not be honored. In time, the reconfigured use of the car is shut down and a different form of the automobile (such as the newer truck) takes over. Hence, the artifact becomes re-stabilized and closure is said to have reoccurred.

EPOR/SCOT provides a framework that research in educational practice can follow. Our introduction above of the gas laws case can be seen as the execution of the first stage. Comparison of the various textbooks demonstrate that there is interpretive flexibility in the manifestation of the gas laws in school science. However, this is not a trivial step. The large degree of black boxing mentioned above means that interpretive flexibility is less apparent. The taken-for-granted nature of much school science content and practice makes establishing the interpretive flexibility of various aspects of school science and teacher practice that much more important for the research program we propose. Exploring interpretive flexibility can show the problematic and contextual nature of content that is usually assumed to be straightforward. On the other hand, closure, at least to some degree, has clearly been reached. There is a fairly stable conception of the gas laws in school science. How did that happen? Why is the conception common to so many chemistry classes the one on which closure has occurred? These are questions for applying the second stage of EPOR to educational practice.

Elements of teacher practice can also benefit from adopting a technological perspective. This should extend beyond the obvious to the myriad of devices teachers use to further their practice. Curriculum guides, lesson plans, tests, demonstrations, rubrics and problem sets can all be instances of technology. They are all solutions to the problem of carrying out school science. Studies following the SCOT model then become appealing. How did a particular technological artifact, such as a worksheet, come to be? Who are the social groups involved in its creation? How do they see the problem?

<div align="center">Black Boxes</div>

A black box is an entity (such as a law, relationship, text, procedure, protocol, technology, device, instrument, etc.) whose validity and internal nature is not in question (cf. Latour 1987, p. 2). The only concerns to a scientist are its inputs and outputs. Latour (1987) illustrates the nature of black boxes by presenting three scenarios separated in time: James Watson and Francis Crick working on the structure of DNA in 1951; Tom West working on the development of the Eclipse MV/8000 computer in 1980; and John Whittaker using an Eclipse MV/8000 to model nucleic acid sequences in 1985. Each researcher has a problem. But what is problematic to Watson and Crick, and to West, is not at all to Whittaker. The double helical structure of DNA has been established as a black box, such that a later researcher need not be concerned with the work done to establish it as fact, but can use it in future work. The MV/8000 is no longer a problem of focus, but a taken for granted tool. This implies a powerful ally. If an element is widely accepted, it is a valuable resource in making future claims. These two examples begin to illustrate the range of elements that often gain black box status. Models, devices, routines, constants, relationships, are all possibilities.

Pinch (1985) demonstrates the immensity of use of black boxes in scientific research. He offers the case of the observation of solar neutrinos. While statements such as "solar neutrinos were observed at such-and-such a rate" are made, this obscures the process of observation. Neutrinos cannot be seen directly. They are detected through their interaction with Cl^{37}, which produces Ag^{37}. But neither can Ag^{37} be directly observed. It is observed by using a Geiger counter to detect the decay of Ag^{37}. This chain continues, until the end result is "splodges on a graph" (Pinch 1985). Each step in this process depends on an array of scientific argument and interpretation. Pinch refers to this as externalization[iii].

> As a way of describing the minimal role played by sense of experience, I refer to the chain of interpretations involved in making an observation as the 'externalization of observation'. To use a biological metaphor: it seems that in scientific observations of this sort our internal biological receptors have become 'externalized'. That is to say, the process of observation in modern science is one in which experimental practices and theoretical interpretations take on central importance. (Pinch 1985, p. 8)

The scientific research is thus impossible without the use of black boxes. This is not simply saying that scientific work often depends on previous work. Rather, scientific work depends on the social acceptance of previous work. There can be different degrees of externality. A report could include the step from Ag^{37} production to its decay, but not the use of the Geiger counter, while another could just declare the observation of neutrinos. The former has a lower degree of externality than the latter. It is a stronger statement, but depends on more acceptance by the recipient.

Likewise, black boxes are not all equal. The use of the Geiger counter to detect Ag^{37} decay is likely to be far more accepted, and therefore a more valuable resource, than the interaction of neutrinos and Cl^{37}. This means that attack on claims are likely to be where argument is not black boxed, or where black boxes can be opened. Black boxes can be used to make statements stronger. Questioning a black box can reduce a previously strong statement's validity.

Central to our argument for the application of S&TS to education is the notion that teachers' practices are filled with black boxes. This continues the explanation for the lack of apparent agonistic process in education. When teachers do not rally resources behind a certain conception of scientific knowledge, it is because the conception they are using has been well black boxed in teacher practice. (Thus, in fact, teachers are employing resources so strong they do not need explicit reference.) The treatment of the gas laws cited above (and that in most high school chemistry textbooks) is an example. Teachers do not need to recreate or defend much of school science, but can readily employ many conceptions. Other examples of black boxes might include a state mandated exam, a textbook definition, or a course sequence. From a research standpoint, however, examination of these black boxes, and their use by teachers (and students), is absolutely necessary for a full accounting of school science teacher practice. The concept of black boxes assists the researcher in avoiding privileging established institutions and authorities.

Schwab's (1964) concepts of substantive and syntactical structures are useful in conveying the range of elements that may be considered black boxes. Substantive structures refer to the theories, principles, and models in a discipline. Syntactical structures refer to a discipline's rules of evidence. Substantive black boxes would include the conceptualizations of scientific knowledge intended for student consumption and the goals of instruction. That knowledge of the gas laws consists of knowing "Boyle's Law," "Charles' Law," and the "combined gas law" would be an example. Syntactical black boxes would include the means for implementing school science.[iv] The ten minute end of the week quiz may be an example of this. However, while these structure definitions are helpful in establishing the range of black boxes, there is a danger in fixating too much on separate categories. Many black boxes (and it is our inclination

to say the most important and interesting ones) clearly cross into both categories. Consider a

typical end of chapter question on the "ideal-gas law equation".

> 10.22 (a) A gas originally at 15°C and having a volume of 182 mL is reduced in volume to 82.0
> mL while its pressure is held constant. What is its final temperature? (Brown and Lemay 1988, p.
> 333)

This is both a substantive and syntactical black box. It is a case of a black-boxed conception of

the intended understanding of the "ideal-gas equation" (to be able to answer a question of this

form). And it is a case of a black boxed device in teacher practice (the missing variable end of

chapter question). Furthermore, it is crucial to recognize the ways in which these two aspects

work together. The conception of understanding here is based on the ability to work with a

certain syntactical device.

<div align="center">Users</div>

Customarily it is presumed that the process of technological design is linear and that it originates

with an idea that results in the creation of a concrete finalized product. However, the design process is

often much more complex. Innovators or designers of technology[v] do more than design a technological

artifact. In designing an artifact with a particular user in mind, they co-construct the user with the

technology (Akrich 1992; Lindsey 2000). Innovators are therefore the producers of the social meaning

of the technology in their social construction of the future user. They "configure the user" (Woolgar

1991) in a context where knowledge and expertise about the user is socially distributed. As a result, the

technology becomes its relationship with the users. Consequently, the technology provides the boundary

between the insiders and the outsiders.

Several studies have investigated how users have employed technologies in ways that have shaped

and/or reshaped artifacts in ways that are distinctly different than those envisioned by the designers. For

example, Pinch and Bijker (1987) demonstrated the impact users had on the social construction of the

bicycle in the late 1800's and early 1900's. Lindsey (1999; 2000) and Kline and Pinch (1996) traced the

life cycle of various technologies into the hands of the users and found that users reconfigured what were assumed to be established stable artifacts.

Lindsey's study of computer users in particular, shows how users can, on multiple levels and in a variety of ways, reconfigure what was thought to be a stable artifact. She describes several different groups of users that have existed throughout the technology's life cycle. These groups fall into two larger categories of users—the constructed users and the actual users. The "constructed user" is the mythical or virtual figure for whom the designers made the computer, that is, the designers' image or representation of the eventual end-user. The "actual user" is represented by the individual who purchased and operated the technology. By engaging with the artifact differently than designers originally intended, these actual users reconfigure the technology.

The actual users took specific actions to change the interpretation and design of the technology. For example, present day users have developed emulators to make modern day computers run like the TRS-80 machines. These emulators form a link between the old and new computers and have resulted in a system that resembles a hybrid between the two technologies. This groups of users exhibit the greatest interpretive flexibility for the original TRS-80 artifact to the point that they have created a new hybrid machine, all the while keeping the old abandoned technology alive and well. In doing so, they have reconfigured the semi-extinct, once stabilized, artifact. Other users have taken another RS technology, the Color Computer (CoCo), and transformed it into a controller rather than comply with its' original intention as that of a home computer. These actions represent the case and point of the unforeseen consequences that inevitably led to the reshaping of the technology (Cowan 1987; Kline and Pinch 1996).

These studies show how various relevant social groups of users reinterpreted and reshaped the technology to a different end than that imagined by the designers. Closure was less defined in

the case of the computer users which leaves open the possibility that the technological process

exists in a continuum of stabilization and re-stabilization.[vi] Additionally, not only did these

various groups' interpretive flexibility alter technologies; their identities were defined by their

relationship to the technologies they used**.** In S&TS, identity is cast as a social construction that

reflects individuals' interactions with other individuals, groups, actors, artifacts, and objects. In

our work, we conceive the notion of identity from a sociological base rather than a psychological

one. Therefore, we rely on Wenger's (1998) interpretation of identity to frame our construct of

teacher/user identity,

> I will use the concept of identity to focus on the person without assuming the individual self as a point of departure. Building an identity consists of negotiating the meanings of our experience of membership in social communities. The concept of identity serves as a pivot between the social and the individual, so that each can be talked about in terms of the other. It avoids a simplistic individual - social dichotomy without doing away with the distinction. The resulting perspective is neither individualistic nor abstractly institutional or societal. It does justice to the lived experience of identity while recognizing its social character—it is the social, the cultural, the historical with a human face (Wenger 1998, p. 145)

> Identity is the vehicle that carries our experiences from context to context (Wenger 1998p. 268)

> Identity in practice is defined socially not merely because it is reified in a social discourse of the self and of social categories, but also because it is produced as lived experience of participation in specific communities. (Wenger 1998, p. 151)

The TRS-80 users changed either the interpretation or the shape of the technology with which they

interacted. Throughout the technological implementation process, users' identities became tied to the

technology they used. Their identities influenced the technology and in turn their interaction and use of

the technology impacted the ways in which they constructed their identities. In the process, the users'

identities are challenged, reinforced, or confirmed (Kline and Pinch 1996; Lindsay 1999).

Lindsey (1999) was able to identify several different groups of users, each with distinct identities

where the users identified with their interpretation of the technology they operated. The "programmers"

for example, associated themselves more with those who knew the workings of the machine, claiming

they were more that just an "end-user". The "experts" (marketers and publishers) separated themselves

from the end-users as well as from the developers by asserting that they had more knowledge and skills

than both the company and the developers. The "tinkerers" and present day users distanced themselves

from the company, the programmers, and the "regular users" because they claimed to be able to "do

more with less by doing real programming with the TRS-80," claiming they knew the guts of the

machine. Their identities were related to, and shaped by, their choice, meaning, and use of the specific

technologies.

Conceptualizing curricula as technologies, we can see the importance of considering teachers'

identities as a part of those technologies. Curricula are designed with an end user in mind, thereby

constructing widely varying identities of the teacher. Some curricula conceptualize the teacher as a near

robotic implementor of the technological artifact, intending for the teacher to follow a formulaic

procedure. Others conceptualize the teacher as an active participant, inviting them to play a part in

shaping the learning process. However, just as with other technologies, the end users often take

initiative to reconfigure both their identity and the technology as a whole. Some teachers make

significant alterations to formulaic technologies. Other teachers adopt the mantel of a straightforward

implementor, thereby altering a technology that originally intended a more diverse implementation.

S&TS in Education

We now turn to specific application of S&TS in education. We begin with comments on

previous work and the rational behind our approach. We then include extensive excerpts from

two ongoing research projects as exemplars of our proposed approach.

Need for Sociologically Sensitive Research Perspective

The most prevalent use of S&TS in education is the formation of the concept of the Nature of

Science (NOS) as a curricular content area. This movement has advocated for inclusion of NOS

issues, such as the tentativeness of scientific conclusions, as a legitimate, and crucial part of the

science curriculum. While this has included research into teachers' knowledge of NOS, this has

been investigated as would teacher knowledge of any other curricular component (cf. Gess-Newsome and Lederman 1993; Abd-El-Khalick and BouJaoude 1997). The second, smaller, area of current use of S&TS is in the investigation of the science classroom as a microcosm of scientific activity. This research has applied the methodological tools of S&TS, and explored the interactions amongst students and between teacher and students (cf. Roth 1992; Kelly and Crawford 1996; Hogan 1999). This has been primarily for the study of student learning.

While these two approaches include the teacher at times, we believe there is a distinct difference with our focus on teacher practice. Such a need is inspired by works such as Shulman (1986; 1987), Lave and Wenger (1991), and Schön (1983), who conceptualize their subjects as professional practitioners. The justification for the use of S&TS is not as a source of content matter, as it is with the first case, nor is it through the classroom as a science making environment. Rather, the justification is through the teacher as a professional practitioner, and a maker of school science knowledge.

Both an advantage and necessity of a perspective such as S&TS is the increasing prevalence of social theories of learning within the field of education. Long dominated by psychological theories, theories that conceptualize learning as a social process are gaining favor (Schön 1983; Lave and Wenger 1991; Wenger 1998). If such frameworks are adopted, it is crucial to also adopt a methodological perspective that is sympathetic to such phenomena. We believe S&TS not only provides such a perspective, but does so in a far more tangible manner than more general ethnographic or qualitative methods approaches. It provides the backing of a significant, rich, and growing research field.

Because S&TS stems from a sociological perspective, it allows for rich and detailed descriptions of actors and practices without bestowing judgement on the actor or the practice.

Focusing on social actions reduces the subjectivity and ambiguity in the research data. Thus, the ways in which teachers present themselves as they "do science," and how they portray science, can be viewed in the explicit social acts they make. Researchers are not dependent on subjects' reporting of their own beliefs. Assumptions can be investigated and actions based on those assumptions can be explained. By looking at actions, and requiring explanations for all actions, the privilege of authority is reduced and observation of all entities—human and nonhuman—can be treated equally (Bijker 1987).

<p style="text-align:center">Programmatic and Normative Context of Exemplars</p>

We now turn to two ongoing research projects to illustrate our approach. Both are situated in Cornell's Environmental Inquiry Projects (see Appendix A). This is a multifaceted professional and curriculum development project that brings together university scientists, science educators, inservice and preservice teachers. At its core is the goal of promoting sociologically authentic science experiences for high school students. Therefore, it takes themes from S&TS not only for research methodology, but also for programmatic design and normative decisions.

We also draw heavily on recent work in situated cognition. Lave and Wenger (1991) present a view of learning based on social rather than psychological dynamics. For them, knowledge and learning is about interaction with others in a particular context. They present learning as *legitimate peripheral participation*.

> It crucially involves *participation* as a way of learning—of both absorbing and being absorbed in—the "culture of practice." An extended period of legitimate peripherality provides learners with opportunities to make the culture of practice theirs. (Lave and Wenger 1991, p. 95)

Newcomers engage in real – i.e. legitimate – work that is connected to the work of *old timers*. In doing so, the newcomers become socialized into the field as their participation becomes more central.

Researchers in science teacher practice has primarily focused on practice within the classroom itself. What has not been examined in the course of these discussions is a focus on the interactions that occur between teachers <u>outside</u> of their classrooms—in professional communities, teacher development programs, or coursework —which influence the ways in which teachers represent science in their classrooms. We know teachers bring experiences, beliefs, and philosophies about teaching science to their classroom environments (Cunningham 1995; Helms 1998); what we do not know, however, is how these constructs and teachers' social experiences in these types of communities effect their classroom practice.

Teachers' work goes beyond the classroom and often includes their participation in settings (such as professional development, curriculum development, conferences, and inservice workshops) that foster teacher-teacher interaction. These types of experiences provide teachers with opportunities to exchange ideas as well as develop materials and activities they in turn bring to their classrooms. It also provides an environment where teachers can network and draw on each other for support and creativity. How and to what extent do these social settings and experiences, and the camaraderie that develops among teachers within these communities, enhance teachers' professionalism and ability to cultivate a social learning environment in their science classrooms? Teachers who choose to teach science as it is practiced in the real world are called on to use approaches that support their students doing original research and open-ended investigations, to put in place practices that encourage student-centered classrooms that provide an environment for public discussion and peer review. Taking this approach requires teachers to take on a more professional and non-traditional method of teaching school science. It requires them to have a strong subject matter knowledge (Carlsen 1988), comfort with laboratory science, and an understanding of science as it is practiced in the real world (Cunningham 1995). In

addition to these perspectives, we illustrate the utility of a COP view in describing classroom

practices and in shaping sociologically authentic school science programs. This view of

learning—as shared participation (Lave and Wenger 1991) in a COP (Wenger 1998)—is a

beneficial way of characterizing what takes place in scientific communities. This perspective is

transferable to the science classroom where learning by participation can also occur and

enhances learning science as it is practiced in scientific communities. Lave and Wenger describe

participation—legitimate peripheral participation (LPP)—as the beginning of the community

membership process:

> It crucially involves *participation* as a way of learning—of both absorbing and being absorbed in—the "culture of practice." An extended period of legitimate peripherality provides learners with opportunities to make the culture of practice theirs. (Lave and Wenger 1991, p. 95)

Wenger describes a COP as being a composite of a shared repertoire, a joint enterprise, and

mutual engagement,

> The repertoire of a community of practice includes routines, works, tools, ways of doing things, stories, gestures, symbols, genres, actions, or concepts that the community has produced or adopted in the course of its existence, and which have become part of its practice. The repertoire combines both reificative and participative aspects. It includes the discourse by which members create meaningful statements about the world, as well as the styles by which they express their forms of membership and their identities as members. (Wenger 1998, p. 83)

> These practices are the property of a kind of community created over time by the sustained pursuit of a shared enterprise. (Wenger 1998, p. 45)

> The first characteristic of practice as the source of coherence of a community is the mutual engagement of participants. Practice does not exist in the abstract. It exists because people are engaged in actions whose meanings they negotiate with one another…Practice resides in a community of people and the relations of mutual engagement by which they can do whatever they do. Membership and community of practice is therefore a matter of mutual engagement. That is what defines a community. (Wenger 1998, p. 73)

We fuse together understandings from S&TS and COP to investigate the formation of teachers'

practice from a sociological perspective. Viewing teachers as makers or "old-timers" and users

or "newcomers" (with regard to their involvement in the EI COP), provides a unique way of

investigating the impact of teachers' social learning experiences on their classroom practice.

The exemplars use a common qualitative collection of methodologies. They use grounded theory, constant comparative analysis, and a case study approach (Glaser 1969; Strauss 1987; Yin 1994).

Exemplar: Inservice Teachers

This research examines the effects of teachers' memberships in communities of practice (COP) on their management of their own classroom communities. Drawing from both the main body of sociology of science and the Social Construction of Technology (SCOT) subfield, this study argues that teachers' use of curriculum can be equated with the use of any technological artifact in an innovative manner (Bijker, Hughes et al. 1999). We view curricula as technologies (Shapin and Shaffer 1985; Mulcahy 1998) and teachers as "users" of those technologies (Bardini and Hovarth 1995; Kline and Pinch 1996; Lindsay 1999). We distinguish between two categories of users: the curriculum "maker" and the curriculum "user." A maker is a teacher who has been involved in multiple phases of the curriculum construction process: design, development, implementation, and evaluation. A user is a teacher who has only been involved in the implementation phase.

EI began with teachers coming to a structured program that focused on fieldwork in environmental science where teachers (users, novices, newcomers) worked with formal stabilized curricular materials. As newcomers or users (configured), teachers worked with environmental science experts and Cornell staff to gain experience working with these activities to facilitate classroom implementation of these materials. This program evolved into a curriculum development project in which several initial participants (users) returned and became makers who would create the EI technology in conjunction with scientists, educators, Cornell staff, and other teachers. The following year, the makers continued to finesse old and new

curricular activities and became the instructors for the new users (newcomers). The makers'

participation in EI evolved from peripherality to full participation and they transformed into

masters within the EI community. In the final formal year of the program, the master/makers

worked on special assignments and continued to assimilate the EI technology into their

classroom syllabi to the point in which the technology became their own (see Appendix A). In

the past year following the end of the formal summer program, teachers have continued to

participate in workshops and to bring their students to the research symposia at Cornell.

The primary subjects of our study are four secondary science teachers who participated in EI.

Two of the teachers (who we have identified as "makers") were selected because in the course of

the interviews, classroom and workshop observations, and ongoing conversations, they came

across as aggressive innovators of curricular projects. However, to situate the teachers in a larger

context, we collected background data from all 14 teachers who have participated in EI. The

other two teachers were selected because of their involvement with the makers during the most

recent summer program and their interest and plan to implement EI materials during the coming

school year. They were participants in a concurrent program and worked with EI teachers in the

afternoons—because these teachers did not design the curricular materials, we have identified

them as "users". All of the summer participants completed a background questionnaire and were

interviewed during the summer program and the school year. Curricular materials were

developed by the teachers during the summers and were collected and analyzed. In addition, site

visits to a subsample of seven teachers' classrooms were conducted last year to gain insights

about curricular implementation and innovation.

This is a piece of a larger study focusing on following teachers through the implementation

of a Bioassay unit. This process took place over a 3-8 week period. This unit was selected

because teachers were concurrently implementing the unit in a variety of classrooms. The

implementations were concurrent because teachers were preparing their students for participation

in a student peer –reviewed Research Congress held at Cornell. Teachers and students were not

only engaging original research experiments (gathering, analyzing, and interpreting their

findings), they were preparing for the project's culmination at the peer review congress.

Participating in this activity required teachers and students to engage in the research process and

find ways to communicate their findings to a larger context. In doing so, teachers were asked to

go far beyond the traditional "cookbook" lab approach to science. This process also involved

teachers' modifying curricula and being open to conducing open-ended investigations in their

classrooms. We followed teachers through this process by visiting their classrooms, conducting

interviews, and maintaining on-going conversations throughout the implementation process. By

focusing on teachers' memberships in COP and their curricular innovations, we examine the role

that identity plays in the teaching of science as a social activity. We are particularly interested in

investigating the ways in which teachers' identities in external COP and as users or makers

translate into their classroom practices. Adopting the practice of following technology users from

SCOT—viewing teachers as users—provides an interesting way to investigate the ways teachers

adopt, integrate, and reconfigure technologies in their portrayal of science. Focusing on users

(and their interactions with technologies) throughout the technology's life cycle offers

provocative insights into teachers' identities as practitioners of science and as members of the

science education community. The level of curricular adoption, integration, and reconfiguration

is used as a measure of teachers' assimilation (buying-in) into COP. Teachers' interaction with

technologies—in the process of making or using—is explored and analyzed by the ways in

which teachers represent themselves when teaching science in a sociological useful way. We are

interested in understanding how teachers formulate their identities as users and makers; how teachers associate themselves with various COP; and ultimately, how teachers' social processes and interactions factor into their classroom practice. Specifically, we ask: What are the effects of science teachers' identities as curriculum makers on classroom practices? Does ownership of curricular methods influence teachers' capacities to foster a classroom COP?

For our work, we utilize the work of Wenger (1998) and Lave and Wenger (1991) to frame our construct of teacher identity and to inform our discussion and portrayal of COP. We employ the work of Lindsey (1999) and Kline and Pinch (1996) to conceptualize our model: Curriculum as technology— Teacher as user.

Several interesting insights about the relationship between teachers' membership to external COP and their classroom practice have emerged. Results support others' findings (Cunningham and Carlsen 1994) that teachers' beliefs about the ability of high school students to conduct "real" science research are shaped by teachers' experiences with science. In this study, all four teachers claimed their research experience in science contributed to their bringing the practice of research and open-ended investigations into the classroom (see Appendix B).

Additionally, teachers saw their strong content knowledge central to teaching inquiry science. Teachers who have been characterized as "makers" tend to draw support from their associated communities of practice and this appears to enhance implementation, innovation, and the creation of a classroom COP (see Appendix B). The makers describe networking with other makers and users at the summer program and school year and events to be both a significant opportunity and a support system for sharing ideas and testing new innovations.

Snapshots of teachers

The teachers in this study were observed over a period of 1-2 months. By spending time in their classrooms and talking to teachers about their practice, we were able to get a sense of their

meanings of practice and their experiences as they implemented the Bioassay curriculum. Below we describe a "snapshot" to represent each of their classrooms and acknowledge their practices as they relate to their COP memberships and their identities as makers and users (see Appendix B).

Andy. Andy is a maker. He has been involved in the design and development of the EI technology from the beginning stages. He has designed and written the curricula for all of his applied science classes. Both his educational and professional background is in chemistry although he does not limit himself to this. He often presents at conferences where he shares his knowledge and expertise in technology, the NYS standards, and in designing science technology and various research projects. Andy has funded his entire computer lab via school grants and outside funding.

A COP exists in Andy's classroom. Andy and his students have developed a repertoire of practice that corresponds to the EI COP and resembles the ways in which science is practiced in the real world. In the course of his students' high school career (in this particular science program created by Andy), they are likely to have him as a teacher for at least 2 out of their four years of science[2]. This has provided Andy with a mechanism to create a COP over time. Students enter the 9th grade class as newcomers to the community and through time, experience, and participation, evolve into old-timers by their senior year.

He teaches non-college bound students, most of who are classified students (resource needs, learning disabilities, Individualized Education Plan), in a dynamic and non-traditional way. He teaches three levels of this class: 9th grade, 11th grade, and 12th grade. For this study, although we visited all three classes, we focused primarily on the senior level class. During a typical day in science class, his 13 senior level students are spread out in 4 different classrooms—a classroom,

a lab, his computer room, or the in the library—each team working on their group projects. Students are given their daily assignments of what they should attempt to accomplish for their portion of the class project during a single class period. Once they get the assignment for the day—off they go. There is a strong sense of respect, comfort, and trust in this classroom. For the bioassay project, students from several of his classes contributed (in the form of research and presentations to other classes) to this overall 12th grade project. This is made possible by Andy's structuring and management of the Applied Science program in his school. Each grade level is organized and specific skills are taught to prepare students for the subsequent year in applied science. Basically, his classroom repertoire resembles a sort of "on the job training" for the next job the following academic year. In the current project, the 9th and 11th grade classes ran many of the preliminary tasks such as preparing solutions and running initial bioassays. The overall project investigated the effects of acid deposition on lettuce seed growth. Students conducted bioassay experiments, created Power Point presentations, and discussed their results and progress electronically with interested scientists and student peers. Their final project involved the construction of an acid rain making device, a poster presentation and a Power Point Presentation of their bioassay results.

Andy's classroom is the exemplar of student- centered inquiry science distinguished through project designs and original research. His enthusiasm and desire to relate the practice of science to the real world shows through in his educational design tactics that center on student life experience and applicability the future workplace or education. This is significant because most of the economy consists of small family farms. His goal of giving students real experiences in the context of science is evident. He asserts "work with their experiences…fit science into their lives." His experience in research and science seem to give him the comfort and confidence to

encourage and facilitate open-ended investigations. His approach of students working and being assessed as effective team members appears to be influenced by his many years participating in athletics and coaching where he emphasizes a work centered attitude. As he describes, "in coaching I like to see kids improve and feel good about themselves—and the same applies to the classroom."

Nigel. After leaving veterinary science, Nigel began teaching high school science. Since he began his career in education 7 years ago, he has been actively involved in presenting at various science education conferences and has been attending summer educational programs on a regular basis. He has been an integral part of the development of the EI curriculum and has written the curriculum for his environmental science classes.

At first glance by an inexperienced observer (who is not familiar with the science classroom), one might see chaos in this classroom. Upon further inspection however, one sees students having fun as they are engaged in their activities. Nigel has two classes of basic environmental science where half of the student population are students with special needs (resource needs, learning disabilities, Individualized Education Plan). In Nigel's classroom, students are free to be themselves. They are busily working concurrently on several ongoing research projects from bioassays to building bio-regulators and composting experiments. Students work in groups under Nigel's guidance. In the case of the first round of the bioassays, none of the lettuce seeds germinated. When students went to inspect their seeds after planting a week earlier, they discovered they had "no results." Nigel used this incident to talk about they way research often goes in the real world, using his earlier career experience in a veterinary science research lab. Nigel went on to say to his students, "this is what it is really like in a real lab…I remember when

all of our animals died in a hepatitis vaccination experiment…and you have to figure out what went wrong and why…what happened today in class actually happens in research."

Ike. After working in various environmental organizations, Ike began his career in teaching. He has been teaching for just over a year. You wouldn't know it when you walked into his ill-equipped science classroom to find students busily working on their bioassay experiments. His students, like the other teachers', are mainly classified students and, like in the other classrooms, are working in groups and getting ready for the research congress. Ike allows them to explore their interests and choose which toxins that want to use in their lettuce seed and duckweed bioassays. He moves around constantly offering suggestions and answering questions. One student works on the only computer in the classroom as she prepares her poster presentation. Ike's students are 9th graders who have been tracked all through school. They sadly refer to themselves as the "dumb ones" but Ike discourages this belief telling them they are doing harder and more time consuming projects than his Regents classes. He informs them how much more time he spends preparing for their class than his other classes. His kids come in every day with positive attitudes, happy, and ready to go. "I have learned to teach a whole different way than the way I was taught to teach—by doing projects these kids will remember what storm water is (that there even is such a thing) and what a lethal-dose 50 means—they'll remember they built devices and [conducted experiments]…more than they'll remember a test they took that day…when they see me excited about being here, they are excited."

Terry. Prior to teaching, Terry was an oceanographer. He has experience in research and has published in this field. Eight years ago, Terry began his career in teaching. This past year, he took over the general science class and decided "enough of the cookbook labs and the textbook-generated curriculum [let's bring research science into the classroom] and a fresh way of

learning for kids." Terry said as he explained to me why he pilots EI and other innovative curricula. He enjoyed his previous work in research and wants to teach kids how to do research. "If the students see me enthused, they become enthused."

Terry directs his students (many of whom are also classified students) and puts them into two large research groups for the bioassays. Although Terry tends to direct students more than the other teachers in this study, he draws upon students' expertise and selects different students to take on leadership roles in the classroom. He selects one student in particular to teach him and the others about using EXCEL in the computer lab. Terry uses this student to help interpret the graphs they have made from the lettuce seed bioassays. Terry sees this as an opportunity for the curriculum to select students and facilitate their strengths and build their self-esteem. Terry adds, "kids appreciate when teachers can get off their pulpits and say let's work on this together…you can teach me…I don't have all of the answers."

EI Teacher Commonalitities

In addition to the visits, on-going conversations, and written feedback, several common themes or ideas emerged from the interviews that are common to all four teachers, which include:

- The intention of making the connection between the real world and classroom science practice.

- Each teacher indicated that when they came to class enthused it generated student enthusiasm.

- Each teacher approached science from an interdisciplinary perspective and worked on making their classroom practice connected to the real world and local environment. They used project-based activities and inquiry investigations to promote understanding and creative thinking and reasoning.

- They presented science as fun, real, and applicable to their students' lives

- Each teacher emphasized the importance of trying out new ideas, taking risks, and of not being afraid to be wrong or making mistakes in the classroom.

- The makers attribute their experiences in the EI COP paramount to their implementation and reconfiguration of the EI technology.
- The users attribute their experiences in the EI COP paramount to their confidence in implementing the EI technology.
- Not working with Regents classes.

Teachers in this study exhibited different levels of implementation and reconfiguration of the EI technology. Although inquiry science is occurring in all four teachers' classrooms, several differences stand out. Andy's classroom has the most extensive and well-established COP environment. His classroom COP repertoire is evidenced by his classes' daily routines. Students interact with Andy and each other as co-workers involved in a common research project. Andy provides support, suggestions, and guidance to his students as they pursue their research ideas. They work in different teams on a weekly basis and collaborate and pool their data regarding their findings that become part of their long-term research projects on local stream ecology and bioassays. From 9th grade on, students learn about the history they will become part of as they progress in their applied science career. They learn how to work in teams, negotiate their respective group and classroom roles and tasks, and present their findings to the advanced classes. Responsibility skills, scientific technique, and being part of a research community are talents that are learned and developed along the way.

Although both teachers focus on project-based science and students doing original research, the frequency and intensity of open-ended investigations and time dedicated to collaborative research projects is higher in Andy's classroom than in Nigel's. Nigel's classroom repertoire is characterized by joint collaboration between research groups within and between his environmental science classes. In taking environmental science with Nigel, students know before hand that they will become part of an ongoing local stream study and will be balancing simultaneous research projects throughout the academic year. They become science practitioners

and are responsible for pooling their data and presenting their results to their classmates and for peer review at Cornell's research symposia. They learn the art of "multi-tasking" and negotiating work with classmates during the course of the year as well how to deal with experiments that go awry.

Both Andy and Nigel have a longer history and more experience (and roles) in the EI COP than Ike or Terry. They tended to run more student-centered classrooms where they took the role of the facilitator and their students were the main practitioners of their classroom science. Whereas Terry's classroom is a more teacher-centered environment, Ike's classroom appears to closely reflects the beginnings of a classroom COP. On a daily basis in Ike's classroom, students are found working in teams on research projects associated with bioassays and studies on their local forest. They create reports and peer review each other's projects and prepare for the research symposia at Cornell. Ike has adopted and implemented protocols, teaching tools, and portions of Andy's classroom repertoire in his own classroom. For example, he uses Andy's teaming approach to students doing groupwork, he has his students prepare PowerPoint presentations of their findings, and interestingly, he can often be heard using language and "classroom talk" that closely resembles Andy's style and classroom demeanor.

Terry, on the other hand, tends to utilize a more structured classroom management approach. However, his students do get the opportunity to work in groups, pool and present data results, and collaboratively put together the findings of their research efforts. Because Terry draws upon the expertise of various students, they have the opportunity to take leadership and teaching roles in the classroom. Additionally, his environmental science class is given the opportunity to have their work analyzed by a local environmental firm which contributes to their ownership and "realness" of their data collection and science practice.

The details of each teacher's classroom COP observations and findings are displayed in Appendix C.

<u>Discussion</u>

Originally we were interested in seeing to what extent users' classroom practice would be different from makers' classroom practice. We were curious to see if being part of a curriculum development program (i.e., Andy and Nigel) would influence the level of technology implementation and reconfiguration in the classroom environment in contrast to users that did not participate in the curriculum development program (i.e., Ike and Terry). Our original hypothesis was that makers would exhibit a higher level of curricular implementation and reconfiguration because of their familiarity with the materials they designed. However, we're not convinced, at this stage in the research, that this is the case (see Appendix C). There are some indications that users may be just as likely to implement and reconfigure with the same rigor as the makers. For example, given enough time and EI COP support, it's reasonable to foresee that Ike will take on the role of a maker in the classroom and mature into a master in the COP community. It conceivable that what we've portrayed here as users are actually future makers. Perhaps a more accurate framework may be to distinguish three groups: makers, early adopters (which would describe Terry and Ike), and users (which would be represented by the traditional teacher). This would recognize that the adoption of the EI curriculum in itself is an innovative act.

Even though we have found this dyadic model (curriculum as technology, teacher as user) to be a valuable tool for articulating teacher practice, it has become rather "messy". As noted earlier, Lindsey (1999) found Woolgar's (1991) boundary between insiders and outsiders insufficient and we are also finding the same applies to our findings. When one follows a technology throughout it's life cycle—into the hands of the user—many different iterations of reconfiguration and user identity occur (Lindsay 1999; Lindsey 2000). In Lindsay's (2000)

research, she found that one group of users reconfigured a technology so much that in time, their knowledge of the technology was so extensive that they came to know the technology better than the original designers. Thus, the boundary between insider and outsider was completely reworked—*the outsiders became the insiders.*

We have seen a similar occurrence in our work. Some of our makers—the masters in the EI COP—through a great deal of crafting and reconfiguration of the EI technology, have come to resemble the users (original outsiders) described above. Arguably, they too have become the new insiders and know the technology better than the original EI staff and others. Through observing and documenting many iterations of teachers making and using technologies, it is becoming increasingly difficult to assign the label user or maker permanently. We have witnessed makers making and using technologies. We have also found that users, on some level (whether it's the addition of white space on an artifact, breaking up a large activity into smaller sub-activities, or a total reinvention of an activity), always reconfigure technology. We also see makers reconfigure a presumably stable technology (see Appendix D). Although we are not ready to abandon this model, we are rethinking how to conceptualize these aforementioned occurrences. Perhaps it is more insightful to look at teachers' interactions with technologies as "using" and "making"; and to examine their identities though their representations of themselves and their portrayal of science in the process of making and using technologies in their classrooms. We have also witnessed users referring to makers, adopting the language of makers, implementing the exact same technologies as the makers, and portraying themselves like their makers they worked with within the EI COP. This illustrates the importance of considering technological frame[3], identity, and negotiations between artifacts and actors. Focusing on the reconfiguration of seemingly stable artifact offers a potentially more useful way of examining teachers' interaction with

various technologies and determining how these interactions function in teachers' identity

construction and in the management of their classroom COP.

Employing this tactic and retracing makers' and users' histories, and refocusing on the role

of reconfiguration, we review one maker's interactions (Andy) with the EI technology and

explore how his membership in the EI COP influenced his technological reconfiguration and

classroom COP (see Appendices D and E).

Andy's case presents some fascinating findings. He has served in many different roles and

capacities in the EI COP: As a newcomer and configured user ; as an actual user who became an

experienced user; as an experienced user who became a configured maker (configured by the

program engineers of EI); a configured maker who became a maker/master; and an expert/master

and an insider who now knows aspects of the technology better than the original EI engineers.

Also interesting to think about is Andy's multiple interactions with the EI technology and how

he represents himself, the technology, and science in the process of using and making the

technology. As a maker, he created several key chapters of EI and while engaging in this design

process, explicitly articulated that his crafting of the technology occurred with his image in mind

as well as the image of the would-be user in mind whom he describes as the "typical teacher". As

Lindsey discovered, it's possible for the original outsiders to become the insiders. This is also the

case with Andy. However, an added twist to this case, is that Andy has functioned as an insider,

a user, and an insider again—through his multiple iterations and reconfigurations of the

technology. Hence, the dilemma in permanently labeling a teacher as a user or a teacher as a

maker. Perhaps, at this point, its valuable to view teachers as *making* and *using* in the

technological design and negotiation process. And consequently, to see makers, users, and the

closure or stability of an artifact as *temporary*.

We have found that teachers who choose to teach science in a sociologically useful way have strong subject matter knowledge, experience with science, and tend to draw upon their memberships in COP for support, ideas, and curricular innovations. Specifically, we have found that teachers who are involved in, and have ownership in, a curriculum development project—over time—tend to implement and reconfigure the curricula when given a medium (such as the EI COP) for collegial support, interaction, and resources to practice authentic science in their classrooms. Employing tools from S&TS and SCOT allows for rich studies of teachers' social interactions with multiple actors (colleagues, staff, scientists, policy) that aid in understanding teachers' actions in their classroom practice. This methodology adds another perspective on viewing the social—in addition to teachers self-reporting of their beliefs, practices, and experiences.

A viable next step in the research process would be to follow the EI technology to completion. Once it is in its final form—as a stabilized artifact, a bound curriculum—following it into the hands of the users may prove to be a fruitful and enlightening study. Utilizing the lens of S&TS and the concept of reconfiguration will enhance our understandings of why and how teachers represent themselves as they portray science in their classrooms.

<u>Exemplar: Preservice Teachers</u>

This research focuses on two projects involving curriculum development with preservice teachers. The first project is a semester-long curriculum design course. It is one of two choices that preservice science teachers have to complete a program curriculum requirement.[vii] However, students are free to take the course at different stages of their program and the course is open to students not enrolled in teacher education. The semester we report on in this paper enrolled teacher education students at various stages (those with little or no education coursework, those

with some coursework but no student teaching, those with student teaching in the last semester of the program), several psychology students, an elementary education student, an English major and a microbiology doctoral student.[viii] The course is designed to provide increasing participation by students in curriculum design. The students' first interaction with schools involved observations and interviews with students, teachers, and administrators, but no teaching. Their second interaction involved teaching a unit designed by the course instructors (including the first author). For the third experience, students worked in groups of 4-6 to design a single lesson within a 3-4 four lesson unit. The topic of the unit and its rough segmentation into lessons was determined jointly by the students and instructors, and was attentive to local environmental issues in cooperating schools. Finally, the fourth experience, encompassing the entire second half of the semester, involved groups of 4-6 designing a full multi-lesson unit. The course has run for several years, each time with some variation in content focus. Here, we primarily focuses on one group, referred to as Group 2, within the third experience.

The course also benefits from being part of the wider EI curriculum and professional development project. This project provides previous designed material, experienced staff, and secondary school partners.[ix] It was a desire to bring the advantages of this association to the formal student teaching experience that spawned the second project, an experimentation with the usual student teaching program. It involved student teachers during a two week intensive workshop immediately prior to their student teaching practicum. The project, dubbed the "Inquiry Project," sought to have students work in collaboration to create a community of practice for their student teaching experience. Students were divided into three groups of 5-6 students, each with a role in supporting a unit using bioassays and peer review (two current interests in the EI project) to study toxicology. Some materials for such a unit had already been

developed as part of the EI project. This paper primarily focuses on the Student Team. (There was also a Teacher Support Team and a Nature of Science Team. Appendix F includes the assignments given to each group.)

History

To orient our discussion, we give a brief history of the work of two curriculum development groups: the Student Team working on the Inquiry Project, and Group 2 working during the Curriculum Design Course. We present them in the chronological order in which these specific groups worked: first the Inquiry Project, and then the Curriculum Design Course. The participants in each project group are listed in Appendix G. (Note that Darrin is a member of both groups. Two other teacher education students participated in both projects, but were not in the groups focused on here.)

Inquiry Project. The charge to the Student Team is shown in Appendix F. The group began with some uncertainty about how to proceed. They quickly agreed that the bioassay materials they had been asked to review were, as Darrin often put it, "too much." They were concerned that the project would overwhelm students. They considered creating their own, smaller packet, or using only some of the material. Ian was an early opponent of rewriting.

Their concern over the amount of material and what to do with it also interacted with early efforts to construct a pretest/posttest. They were concerned with how the test would match with the provided instructional materials or whatever substitute they constructed. However, this led to a realization that the pretest/posttest was not supposed to be a test of coverage, but of students' conceptions. This allowed the group to disentangle the problem of what content the material (or a successor) would cover from the problem of what content would be relevant to the test. Nevertheless, the content of the test itself remained problematic. Of particular concern was how

to test for certain understandings without depending on other knowledge, particularly of technical terms.

Their work with the bioassay materials meanwhile became more intertwined with other tasks. While various degrees of reworking were proposed, the preservice teachers' general concern was for making something more palatable for students. Nate made a connection between this general concern, and another assigned task of adapting material for a special needs group. He proposed, and the group agreed, to create a 4-5 page version aimed at weak readers, but usable by all students.

Work on the test continued with concern over using terms (e.g., "toxicity") with which students might have a variety of conceptions. Discussion on test items involved fluctuation between various proposals by group members until a question was formed that focused on the target conception. Thus, for example, they formed as their first question simply, "How do you know if something is toxic?" During a discussion with all three groups, one of the course instructors pointed out that in everyday life, knowledge of toxicity often depends on trust in others. This led to an alteration of that question into asking students how they would explain the word "toxicity" on a warning label directed to a younger sibling. The instructor also suggested use of a scenario to test students about bioassays. The group used this suggestion to form the remainder of their test.

Finally, the adaptation of the bioassay materials made one final shift. The group decided, rather than making 4-5 pages of written text, to make a series of handouts/overheads that would guide class discussion. This was influenced by a desire to provide tools for teachers' lectures, a concern for weak readers, a perception that this was an easier way to reach consensus on what to include, and, perhaps most of all, a concern that the group was running out of time. The Student

Team's final product consisted of a pretest/posttest on student conceptions of toxicity and bioassays, and a series of handouts/overheads covering the main points of conducting a bioassay experiment.

Curriculum Development Course. For the year reported here, the Curriculum Design Course focused on urban water issues, in part due to the location of the cooperating school. For the third experience, where the class divided into several groups to each design a single lesson within a common unit, the class as a whole decided to design a unit focusing on pollution in a river in the city where that year's cooperating school is located. This decision was motivated primarily by the school's students citing river pollution--especially leakage from a particular company's chemical storage tanks--as a local environmental problem. After brainstorming possible activities, the course instructor (the first author) proposed the following three lessons: 1) an informational overview providing a history of the problems; 2) a lesson teaching concepts of concentration, possibly including a physical manipulative; 3) a lesson involving physical modeling of the storage tank leakage. The deliberative process undertaken by the curriculum design students is exemplified in their planning for the second lesson.

Group 2 began with a focus on "parts per million," and established that understanding as a conceptual goal. This led to a consideration of various materials that could be used as examples, including money, Kool-Aid, and sprinkles on brownies. The students also considered whether and how they could demonstrate bioaccumulation and chronic versus acute doses, and whether to talk about specific, real toxins. The "ppm" notation remained an assumed central component of the content.

At this point, two members of the group, Merideth and Lou, had an opportunity to meet with an emeritus professor in the Department of Education who has significant expertise in teaching

difficult scientific concepts through everyday, hands-on experiences. They described their idea of modeling concentration using number of sprinkles per brownie and Kool-Aid. The professor pointed out that neither of those substances is really toxic to students. He suggested showing battery acid being diluted with water, and asking students when they would be willing to drink it. He also suggesting a discussion of where a glass of water came from. However, the two students related none of these ideas into the general discussion when the group next met. Meanwhile, Group 3 made a change from modeling the cause of river pollution to modeling methods of cleaning up a polluted river. This change had little effect on Group 2, but a later shift by Group 3 would be more significant.

Group 2 continued trying to develop an activity demonstrating parts per million. They struggled with how to connect the logistics of preparing solutions (scoops of Koolaid per gallon of water, mg per liter) and the ppm notation. For the Koolaid, they were envisioning having students prepare their own preferred concentration, and create dilutions from there. They were also concerned with matching up their lesson with the preceding and following lesson. It also occurred to the group to consider what would and would not be necessary given the previous understanding of the students. This led first to expanding the focus to toxicity rather than just concentration, and in turn, to considering including a daphnia bioassay. Bioassays had been previously mentioned by Darrin, recounting his experiences with students' conceptions of concentration during the Inquiry Project.

At this point, the group grew concerned with the time necessary to include a physical manipulative demonstration, a dilution activity, and a bioassay, and started to consider logistical ways of accelerating the activities. The connection with toxicity and the real world continued to

be a concern. They struggled with the issue that a preferable mix of Koolaid is safe for humans but toxic to daphnia.

Meanwhile Group 3, having struggled with how to model river cleanup, independently came up with a redesign for the three lesson sequence that involved starting a bioassay on the second day. This stabilized Group 2's plans for both the preparation of a standard dilution and the testing of the dilution on daphnia. Finally, the group settled on using a mixture of black beans and white beans (different numbers of black beans in a Ziploc bag full of white beans) for a visual illustration of concentration.

Discussion

We now present six general themes exemplifying our theoretical and methodological perspectives.

Cases of Legitimate Peripheral Participation. Each project was a successful case of Lave and Wenger's notion of legitimate peripheral participation. The work was real – in both cases they were preparing curriculum for actual students. This legitimateness included the problematic elements of the field. Participants struggled with factors such as time, variation in students previous experiences, and linkages to other parts of the curriculum.

Each project also included varying degrees of centrality in their participation. No groups started from scratch. The Inquiry Project explicitly asked participants to work from the products of previous endeavors by more experienced teachers and university faculty. During the Curriculum Design Course, participants go through a sequence of experiences of increasing involvement: they start with a guided needs assessment visit to the cooperating school; conduct a lesson designed by the instructors; design a lesson within a framework guided by the instructors; and finally, design an entire unit.

Both groups also had access to a variety of expert individuals. The instructors played a more formal role of old-timer, but other people – education faculty, secondary school teachers, science researchers – provided critical connections. It is also significant to point out the varying degrees of expertise amongst the students themselves, particularly within the Curriculum Design Course. By not requiring students to take it at a certain point in their program, and by being open to others, the participants themselves represent a range of comparative newcomers and old-timers in a variety of fields.

Interpretive Flexibility and Closure. The groups' curriculum development work exhibited cycles of variety and stabilization, as described by SCOT. Participants would exhibit interpretive flexibility with regard to solutions to their present problem, engage in social negotiation, and eventually reach closure on a particular conception. For example, the Student Team was initially uncertain what their charge of "Reviewing materials for student use" would entail. This quickly stabilized on some form of simplifying the present materials. How to do so became the new problem for which there was initial interpretive flexibility. A 4-5 page version and then a series of handouts/overheads were two subsequent points of stabilization.

It is important to emphasize that interpretive flexibility is not simply variation in preferences for solutions to a particular problem. Such a view presumes too much of a uniformity in perspective amongst participants. Rather, the flexibility encompasses conceptions of the problems themselves. For example, different participants had different conceptions of what "concentration," as a topic of instruction, entailed. Some considered it equivalent to use of the "parts per million" notation. Darrin, on the other hand, considered it crucially linked to the idea "the dose makes the poison" - a theme from EI materials.

In their negotiation, participants used allies and artifacts to support their particular position. In presenting an explanation of ppm, Ellen made reference to "my PI[x]." During his work in the Curriculum Design Course, Darrin, the student who had done bioassay experiments in his student teaching made several references to that experience, particularly with regard to student understanding. There were also instances of failures in social negotiation. The two students who met with the emeritus professor were the weakest students in Group 2. Thus they were unable to introduce any of those ideas.

Opening Black Boxes. The social work provided significant opportunities for opening black boxed conceptions – those conceptions who's internal structure is well established and otherwise left unexamined. One of the concerns driving both of these projects was that teachers, particularly preservice teachers, often simply implement black-boxed entities without developing an effective understanding of the material themselves (See Figure 1, in Appendix H). Work involving social collaboration is considered a solution to this problem by providing a forum for black-boxed concepts to be re-addressed (See Figure 2, in Appendix H). Appendix I shows a portion of the Student Team's discussion about the term "toxic" that occurred during their efforts to construct the pretest/posttest. In having the discussion, the students directly address a typically taken for granted notion.

Several additional points, however, need to be made with regard to this process. First, it is unclear if students have the necessary tools to effectively reach closure once such black boxes are opened. For example, in considering a special needs group, the Student Team had a discussion similar to the toxicity converation concerning the meanings of the terms "ADD" (Attention Deficit Disorder) and "ADHD" (Attention Deficit Hyperactive Disorder). While the students arguably have fair amount of expertise to address the toxic issue (and eventually

consulted a dictionary), they had little expertise to address this issue. However, their means of closure, namely one or several students presenting a plausible sounding explanation, was used in both cases. Time, or lack thereof, was also often a significant means of closure.

Second, not all black boxes get open. Of course, it should be pointed out that doing so would be counter productive, and likely impossible. However, there were instances where, despite the use of significant black boxed concepts in social collaboration, the inner structure of those concepts was left un-addressed. For example, while the ppm notation eventually fell out of the design of the Group 2 lesson, the participants never discussed why that notation and concept is used in science.

Third, stabilization is not deterministic. The participants are not simply rediscovering old ideas in predictable ways. For example, by chance, both groups (the Student Team and Group 2) opened up the black box of the daphnia bioassay. Both groups addressed the questions why are daphnia used, and what is the connection between toxicity for daphnia and toxicity for humans. However, each groups reached closure on a different concept. The Student Team concluded that daphnia have logistical advantages (short lifespan, cheap, observable physiology). The Curriculum Develop Course participants as a whole settled on the explanation that daphnia are part of the base of the food chain, and therefore tests of daphnia are in part, tests of the ecosystem as a whole. A significant factor in this form of closure was a student (not in Group 2) whose technological frame included a concern for installing ethical considerations into scientific work. For her, using daphnia as an indicator species was a more viable point of closure than as a convenient experimental organism.

Technological Frames. As illustrated by the previous example, students exhibited different and significant technological frames – that is, characteristics of a participant's orientation

towards the design process. Such frames do not have to be in conflict in order to be different. In Group 2, several students included in their frame a view by which their charge of designing a lesson on concentration meant teaching ppm. However, this stemmed from different sources. Ellen, the microbiology doctoral student, for example, felt that ppm is the essence of concentration. For her, the two were inseparable, exclaiming at one point, "but that [ppm] *is* concentration." For Meredith, however, her concern was students' scientific literacy. She felt students should know what ppm meant for when they see it in the media.

Unfamiliarity with Legitimate Practice. Students occasionally exhibited an awkwardness or uneasiness with the ambiguous or open nature of their work. Most groups started out questioning what their task was. This was not simply an unawareness of the task itself, but an unawareness of the role they play in determining the task. On the other hand, there were clear instances where participants realized their control of their work.

Groups occasionally found difficulty in moving from a point of closure to the next stage of their work. Essentially, while they had reached closure, they were unaware or unsure that they had. For example, Group 3, when focusing on cleaning up river pollution, realized that not knowing what were some of the real pollutants was inhibiting their attempts to come up with modeling strategies. However, they continued to deliberate over possible strategies rather than research the river pollution.

This does not mean that groups remained aimless. However, when there was such a transition, it was often aided by a meta level action. For example, Nate would often make a summary statement. This was also a significant role for the instructor during the Curriculum Design Course. Such roles were examples of newcomers' work being aided by old-timers.

Interdependence. There were instances of interdependence, both between groups and between tasks within a group. Significantly, students were aware and concerned with addressing such interdependence, particularly with the Curriculum Design Course, where the different group projects where intended as a unified unit.

This interdependence had a significant effect on the stabilization of group work. For example, while Group 2 independently considered incorporating a bioassay, the proposal by Group 3 did much to stabilize their decision and the particular design of their lesson. For the Student Team, their linkage of the special needs task with the material review task also was a stabilizing factor for their work.

Summary

In general, we found these projects to be a productive application of our theoretical perspective for both programmatic and research interests. When student engage in legitimate curriculum design, significant social learning takes place. Students moved from being non-professionals to newcomers in the field of curriculum design. The SCOT model of alternating variety and stability provided a enlightening framework for investigating participants' work.

Conclusion

We have put forth a methodological perspective, through the adaptation of themes from Science and Technology Studies, that we believe can be extremely productive for studying the practice of teaching. We end by noting four central advantages. First, by being situated in sociology and focusing on actors, artifacts and agency, it diminishes the reliance on external proxies necessary in psychologically based work. The interest is directly in what people do; not in the internal state that actions may be indicating. Besides the methodological difficulty inherent in probing psychologies, we find it far more fruitful to ask what are people doing than what are people thinking. Beliefs, knowledge and understanding are only meaningful in the

manner that they effect the external world. Second, the S&TS perspective promotes and

necessitates explicit attention to taken-for-granted notions present in the practice being

researched, and is extraordinarily illuminating in the description of phenomena it builds. The

defining characterization of S&TS is the need to provide a full sociological explanation. Its

development in the context of studying science has yielded an enviable rigor.

> The political vulnerability of one of the few sociological specialties that, so to speak, "studies up,"
> that aims to interpret a culture far more powerful and prestigious than itself, and that offers
> accounts at variance with that culture's official myths, is only now being made manifest. As the
> Chinese proverb has it, he who rides on the back of the tiger may wind up inside. (Shapin 1995, p.
> 292)

We find the track record of S&TS to be extremely productive in the study of institutions such as

teaching (one arguable "more powerful" as well). Third, S&TS is attentive the dialectical and

situated nature of reality. Internal conception and external reality are simultaneously formed as

products of one another. Much of present reform efforts appear to be focused on creating clear,

linear machinery for producing instruction. Despite such efforts, we are convinced teacher

practice is far more complex and subtle. Content matter, for example, is not something

externally definable against which teacher knowledge can be easily compared. It is interesting to

compare the focus on content between the research programs in the sociology of scientific

knowledge and pedagogical content knowledge. Consider for example, the following critiques

of preceding work, each by a leading proponent of the respective fields.

> This program [the sociology of science] does not require sociological attention to the content of
> scientific answers. It might be possible to say something about the direction of scientific inquiry,
> but the answers become interesting to the sociologist only if they are wholly men's answers rather
> than Nature's – that is to say, if they are not "properly" a part of scientific knowledge. In the
> main, the content of scientific knowledge remains a closed book within this enterprise. [See
> Merton (1945) for a programmatic discussion.] The sociology of scientific knowledge, on the
> other hand, is concerned precisely with what comes to count as scientific knowledge and how it
> comes to count. (Collins 1983, p. 267)

> Occasionally subject matter entered into the research as a context variable – a control
> characteristic for subdividing data sets by content categories (e.g., "When teaching 5th grade
> reading,…"). But no one focused on the subject matter content itself. No one asked how subject
> matter was transformed from the knowledge of the teacher into the content of instruction. Nor did

> they ask how particular formulations of that content related to what students came to know or misconstrue. (Shulman 1986, p. 6)

Hence both research programs are interested, not just in content matter, but in the particularities of content matter and how they make a different. They understand that knowledge is situated, and deem that important to the wider endeavors in their respective fields. Lastly, we find utility in the rigor provided by having Science and Technology Studies available as a defined discipline, with institutions, literatures, and knowledge bases, in preference to a looser conglomerate of qualitative methods.
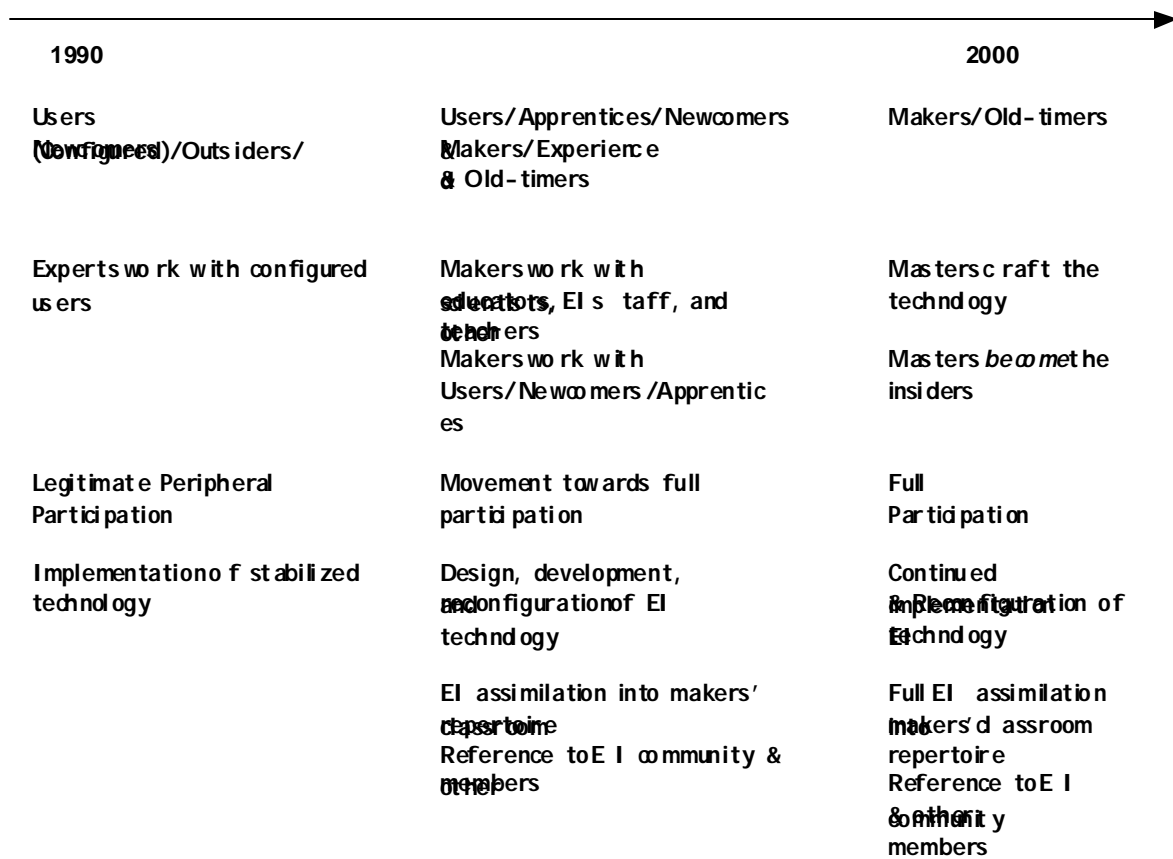
Appendix A - Overview of Environmental Inquiry

Environmental Inquiry (EI) is a NSF-funded secondary school curriculum development project dedicated to the creation, evaluation, and distribution of sociologically authentic environmental science materials. An important goal of EI is to enable students to engage in science as it is practiced in the real world. Students study environmental science content through immersion in local projects that require scientific work and student involvement in several layers of "community," including the classroom, the local geographic/political region, and a community of peers engaged in similar studies elsewhere. For example, as teachers involve students in biological control experiments or watershed land use analysis, students will conduct interviews, gather data, and present their findings to local agencies, such as school and town boards and planning committees. By taking these action steps, students will gain exposure and experience in both the micro- and macrosociological perspectives of science-- science as it occurs in the real world. EI differs from most formal science programs at the high school and college level in its emphasis on the sociological nature of science.

The curriculum is organized around a series of investigations (laboratory, field, and simulation studies) that progress from standard-method "Protocols" (e.g., the utilization of a well defined procedure to assess the toxicity of road salt to lettuce seeds), through "Explorations" (e.g., relatively informal and divergent mini-studies of the toxicity of other environmental chemicals to lettuce seeds), to "Interactive Research" projects (e.g., students collaborating with students at other schools through peer review, web-based research projects, or large-scale action projects). Table 1 displays these three levels of investigation as column headings, and arrays some salient investigation features, targeted sociology of science concepts, and example student experiences.

Three levels of investigation in the Environmental Inquiry project.			
	Protocols	**Explorations**	**Interactive Research**
Features	Fixed procedures techniques, limited variables, identification of problem spaces, standards	Flexible, imaginative, creative, unknown outcomes	Maturation, accountability, action steps, peer review
SOS concepts	Building on other research, replicates and replications, controls, scientific theory and method, collaboration, interdisciplinary, locally situated	Messy data interpretation, open-ended questions, negotiation, groupwork, brainstorming, deciding what to study	Political influences, economic influences, politics, status, images of science, current science issues and events, networking
Projects, activities, and experiences	Mastery of skills, managing a problem space, developing an experimental framework, determining what is plausible	Open-ended questions and unknown outcomes	Presentations, internships, partnerships

EI COP

Evo lu tio n

1990		2000
Users (Configured)/Outsiders/ Newcomers	Users/Apprentices/Newcomers Makers/Experience & Old-timers	Makers/Old-timers
Experts wo rk with configured us ers	Makers wo rk with educators, EI s taff, and teachers Makers wo rk with Users/Newco mers /Apprentic es	Masters c raft the techno logy Masters *beco me* the insi ders
Legitimat e Peripheral Partici pati on	Movement tow ards full partici pati on	Full Partici pati on
Implementationo f stabili zed techno logy	Design, development, and reconfiguration of EI techno logy EI assimilation into makers' classroom repertoire Reference to E I co mmunity & other members	Continu ed Implementati on & Reco nfiguration of EI techno logy Full EI assimilation into makers' cl assroom repertoire Reference to E I co mmunit y & other members

Appendix B - EI Teachers

Teacher Background & Experience with Science				
	Makers		**Users**	
Teachers	**Andy**	**Nigel**	**Ike**	**Terry**
Educational background	B.S. Chemistry Graduate work in Chemistry	B.S. Biology M.S. Education	B.A. Biology MAT Biology	B.S. Geology MAT Earth Science
Previous Career	Pharmaceutical Chemist	• Veterinary Technician • Marine Biology research	• DEC • Environmental firm	Geologist
Experience with Science	Conducting bioassays in pharmaceutical lab	• Research in Marine Biology • Research in Vet. Sci.	Research in Environmental Science	Research in Oceanography

COP				
	Makers		**Users**	
Teachers	**Andy**	**Nigel**	**Ike**	**Terry**
COP Membership	EI, ISET, grants (NSF& technology), coaching, curriculum committee, conference presentations	EI, CIBT, NSTA, STANYS, staff development leadership, environmental awareness club w/students, conference presentations	Trout Unlimited, Greenpeace, National Wildlife Federation, ISET Coaching, interest in starting Ecology club	ISET, STANYS, Earth Science Mentor Network, conference presentations, Envirothon, research & publication
Attributes Gained from COP	EI & ISET: sharing ideas, interaction with other teachers interested in creating curricula Grants: access to technology & networking/ communication via the web Coaching: teaming and groupwork	EI, CIBT, NSTA, STANYS: curricula for new approaches to science teaching, presentations, keep up to date on current research Prof. Dev.: presentations, leadership	Trout Unlimited, Greenpeace, National Wildlife: Stewardship skills, environmental awareness ISET & CIBT: ideas & innovations, curricular materials	ISET, STANYS, Earth Science Mentor Network, conference presentations: latest research, colleagues' experiences, new teaching methods, NYSED updates

Teacher Identities				
	Makers		**Users**	
Teachers	**Andy**	**Nigel**	**Ike**	**Terry**

Major Influences on Classroom Practice	• Coaching • Workplace skills • MST Standards • Students • Kinesthetic learner • Philosophy about teaching science	• Professors & education programs • Research experience • Mentor teacher (impetus to teach differently than mentor)	• Professors • Personal graduate school experience • Research and career experience • Activity instead of boredom • Desire to take risks and try new activities	• Professors • Research and career experience • Philosophy about science
Beliefs about Teaching Science	• Inquiry science • Open-ended investigations • Students doing original research • Application to students' lives and experiences • Ability to make connections	• Activities – students (and teacher) need to move around • Teach science as science is practiced – bring current research into the classroom • Students doing original research • Open-ended investigations	• Activities • Hands-on • Working in groups • Open-ended labs (85%) • Thinking & reasoning skills • Work with current research • Ability to make connections	• Real research • Teaching science as science is practiced • Relevance to local environment • Science is an activity of discovery, encouraging curiosity, and figuring out patterns
Classroom Practice	• Teaming • Student centered, limited lecturing • Incorporating students' life experience • Job and workplace skills • Practice real world science—application to students' lives • Project-based learning • Technology rich • Less emphasis on grades – multiple assessments • Willingness to experiment with new ideas and activities—not concerned with failure	• Groupwork • 30-50% lab • 50-70% lecture • project-based labs • self-designed curricula • Practice real world science— application to students' lives • Less emphasis on grades • Willingness to experiment with new ideas and activities—not concerned with failure • Learn from students	• Behavior modification • Learning skills • Conflict negotiation • Workplace skills • Character education • Less emphasis on grades – multiple assessments • Inquiry based • Willingness to experiment with new ideas and activities—not concerned with failure • Learn from students	• Empower students— ownership of the data • Hands-on and minds-on • Allow the curriculum to select for students' various strengths • Multiple assessments • Inquiry science but teacher directed

	• Learn from students			
Instructional Design	• Projects • Teaming • Student centered • Multiple assessments—akin to the workplace • Flexibility • Activity-based (kinesthetic) • Student presentations and peer review • Students working concurrently in 4 different classrooms & labs	• Multiple assessments • On-going Projects • Flexibility • Activity-based • Structured • Student presentations	• Multiple assessments • Projects • Flexibility • Activity-based • Achieve understanding and making connections between and within science content • Connect experiences • Two-way between teacher and students • Posters and student presentations	• Groupwork • Labs and hands-on activities • Teacher directed • Open-ended investigations • Student presentations

Insights & Emergent Themes				
	Makers		**Users**	
Teachers	Andy	Nigel	Ike	Terry
Insights	• Teacher enthusiasm = student enthusiasm • Students work together (prepare for careers) • Not afraid to make mistakes and have students correct • Life skills and science skills • Have students teach each other • Students in leadership roles in the classroom • On-going and concurrent long-term projects	• Willingness to experiment and try new ideas • Not afraid to make mistakes and have students correct • Life skills and science skills • Learn from students • On-going and concurrent long-term projects	• Teacher enthusiasm = student enthusiasm • Willingness to experiment and try new ideas – take risks • Not afraid to make mistakes and have students correct • Life skills and science skills • Learn from students • Have students teach each other • Students in leadership roles in the classroom	• Teacher enthusiasm = student • Make it fun • Take risks • Encourage 9th graders—"don't decapitate them" • Willingness to experiment and try new ideas • Students in leadership roles in the classroom

Appendix C - EI Teachers' Classrooms

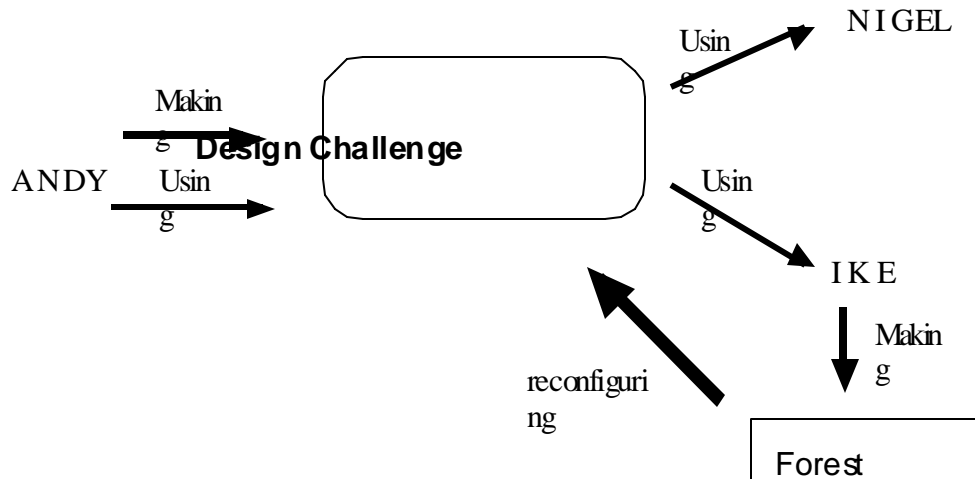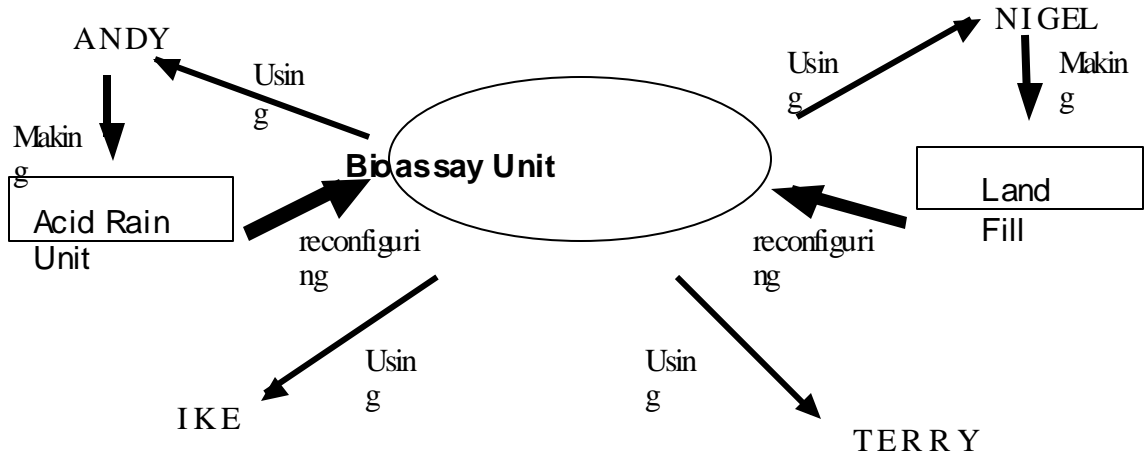| Repertoire of Classroom COP	
Teacher	Repertoire
	Routines, works, tools, ways of doing things, stories, gestures, symbols, genres, actions, or concepts produced & adopted by the community.
Andy	Daily team assignments (groupwork); PowerPoint presentations; weekly class presentations/updates; simultaneous use of different classrooms spaces; concurrent interclass & inter-group collaboration on class research projects; student roles & establishment of identities within the classroom community—as tool makers, lab specialists, and technology experts; inter-and individual class research project updates posted on the class's web page and the EI web site; common & consistent reference to EI community & Cornell; electronic communication within outside scientists.
Nigel	Interclass & inter-group collaboration—pooling data; posting research results on the EI web site; reference to the EI community; culminating class presentations.
Ike	Team assignments (groupwork); reference to EI community; Cornell; and specific EI makers; PowerPoint presentations.
Terry	Reference to EI community; Cornell, and specific EI makers; student roles & establishment of identity—drawing upon students' expertise.

Shared Enterprise of Classroom COP	
Teacher	Shared Enterprise
	Practices that become the property of a community created over time.
Andy	Structuring of the applied science program so that each grade level prepares for the next grade level via "sub-contracting" of lower grade levels working for Senior level classes in collaborative research projects. Thus, students anticipate their roles as they progress in their high school career; teaming; on-the-job teacher and peer expectation; local stream studies; student original research and presentations at Cornell's student research symposia.
Nigel	Local stream studies; community action; student original research and poster presentations at Cornell's student research symposia.
Ike	Local forest study, working with local environmental agencies, teacher-guided (moderate) student original research and poster presentations at Cornell's student research symposia.
Terry	Local stream study, working with local environmental agencies, teacher-guided (strong) student original research and presentations at Cornell's student research symposia.

Mutual Engagement in Classroom COP	
Teacher	Mutual Engagement
	People are engaged in actions whose meanings they negotiate with one another.
Andy	Classroom expectations & goals; work-centered classroom structure & management; class projects and group and student roles; peer review; what work and scientific research means in the classroom.
Nigel	Classroom expectations & goals; peer review; responsibility; what work and scientific research means in the classroom.
Ike	Classroom expectations & goals; class projects; peer review; what work and scientific research means in the classroom.
Terry	Classroom expectations & goals; what work and scientific research means in the classroom;

Legitimate Peripheral Participation in Classroom COP	
<u>Teacher</u>	**Legitimate Peripheral Participation**
	A process by which newcomers become part of a COP—acquiring a mastery of knowledge and skill—a way to speak about the relations between newcomers & old-timers, activities, identities, artifacts, and COP.
Andy	LPP in 9th grade to full participation by 12th grade. Transformation of students from novices/ newcomers to master/old-timers
Nigel	Student full participation by end of year; experienced practitioners and some masters
Ike	LPP in beginning of school year to moderate LPP by the end of the school year. Novice/newcomer to qualified apprentice.
Terry	LPP, novice

Appendix D - EI Teachers' Technology Using and Making

Teachers as Users--Curricula as Technologies
Using, Making, & Reconfiguring Curricular Artifacts

ANDY

Using

Making

Bioassay Unit

Acid Rain
Unit

reconfiguring

IKE

Using

NIGEL

Using

Making

Land
Fill

reconfiguring

Using

TERRY

Making

Design Challenge

ANDY

Using

NIGEL

Using

Using

IKE

Making

reconfiguring

Forest

Reconfiguring the EI Technology

EI COP

Andy

EI
small, informal, intentional,
& highly structured

configured user/
newcomer

Andy

using

classroom implementation

experienced
user

EI
larger, formal,
& intentional

Andy -
"configured
maker"

making

using

Classroom
implementation &
Reconfiguration

making

using

EI
informal &
organic

Master
Old-timer

reconfiguration & negotiation   reconfiguration & negotiation

Appendix E - EI Teachers' Participation

EI Timeline	*Andy's participation in EI COP*
Summer 96	Participated in structured professional development activities that focused on watershed dynamics.
School year 96-97	Implementation of watershed dynamics curricular activities.
Summer 97	Participated in the EI curriculum development inservice program. At the request of the project co-director, designed and developed a design challenge (water sampler) packet for the Watershed Dynamics chapter of EI. This was used as the featured activity and protocol for the Student Design Challenge competition hosted at Cornell the following Fall.
School year 97-98	Implemented and reconfigured the design challenge activity by making it more open-ended for his students. He added changes to the original packet. Piloted other EI members' work on Bioassays.
Summer 98	Participated in the EI curriculum development inservice program. At the request of the project co-director, designed and developed another design challenge (storm water retention model) packet for the Watershed Dynamics chapter of EI and this was also used in the Fall for the 2nd Student Design Challenge competition hosted at Cornell. Piloted and reconfigured the Bioassay unit by making the activities more open-ended and project centered (tied in local stream ecology, water chemistry).
School Year 98-99	Implemented and reconfigured the design challenge activities by making them more open-ended for his students and enlarging the project to include stream chemistry and water pollution. He added changes to the original packets and they were assimilated into the EI Technology. Continual piloting and reconfiguring of the Bioassay unit by making the activities more open-ended and project centered (tied in local stream ecology, chemistry, acid precipitation, soil chemistry). Had students fully engaged in the on-line peer review component of the bioassay unit in preparation for the research congress at Cornell. The bioassay unit and the design challenges have been assimilated into the Applied Science program.
Summer 99	Worked as a consultant (master) to finesse the Bioassay peer review web-site at Cornell making it more user friendly to teachers.
Current - ongoing	Continued reconfiguration of EI technology and participation in workshops in the EI COP.

EI Timeline	*Nigel's participation in EI COP*
Summer 96	Participated in structured professional development activities that focused on watershed dynamics.
School year 96-97	Implementation of watershed dynamics curricular activities.
Summer 97	Participated in the EI curriculum development inservice program. At the request of the project co-director, designed and developed a curricular unit on bioremediation and composting.
School year 97-98	Implemented and reconfigured the bioremediation and composting activity by making it more open-ended for his students. He added changes to the original packet. Piloted other EI members' work on Bioassays and the design challenge units.
Summer 98	Participated in the EI curriculum development inservice program. At the request of the project co-director, designed and developed a curricular unit on GIS. Piloted and reconfigured the Bioassay unit by including a landfill design component. Worked as a Master with newcomers in the afternoon sessions.
School Year 98-99	He added changes to the original packets and they were assimilated into the EI Technology. Continual piloting and reconfiguring of the Bioassay unit. Had students involved in the on-line peer review component of the bioassay unit in preparation for the research congress at Cornell. The bioassay unit and the design challenges have been assimilated into the Environmental Science program (Basic & AP).
Summer 99	Worked as a consultant (master) to finesse selected EI curricular activities
Current - ongoing	Continued reconfiguration of EI technology and participation in workshops in the EI

	COP. Currently on sabbatic leave from teaching—is a Fellow in the EI program at Cornell.

EI Timeline	Ike's participation in EI COP
Summer 98	Participated in structured professional development activities that focused on watershed dynamics in the formal section of EI. Worked with Masters in the afternoon on specific curricular topics (water design challenge—with Andy).
School Year 98-99	Implemented water design challenge activities and Bioassay units. Reconfigured Bioassay units to include local forest study. Students participated in Cornell's Design Challenge and Research Symposia.
School Year 99-00	Students participated in Cornell's Design Challenge and Research Symposia\
Current - ongoing	Continued implementation and reconfiguration of EI technology and participation in workshops in the EI COP.

EI Timeline	Terry's participation in EI COP
Summer 98	Participated in structured professional development activities that focused on watershed dynamics in the formal section of EI. Worked with Masters in the afternoon on specific curricular topics (Bioassays).
School Year 98-99	Implemented water design challenge activities and Bioassay units. Students participated in Cornell's Design Challenge and Research Symposia.
School Year 99-00	Students participated in Cornell's Design Challenge and Research Symposia.
Current - ongoing	Continued implementation and reconfiguration of EI technology and participation in workshops in the EI COP.

Appendix F - Inquiry Project Team Charges

Student Team – Responsible for resources related to student understanding. This includes (a) Reviewing materials for student use; (b) Developing a web-based pretest/posttest to gauge students' understandings of toxicology and bioassays; (c) Identify one or two special needs student populations (e.g. one language minority group and one specific learning disability), and (d) Adapting selected instructional materials for use by those special needs populations.
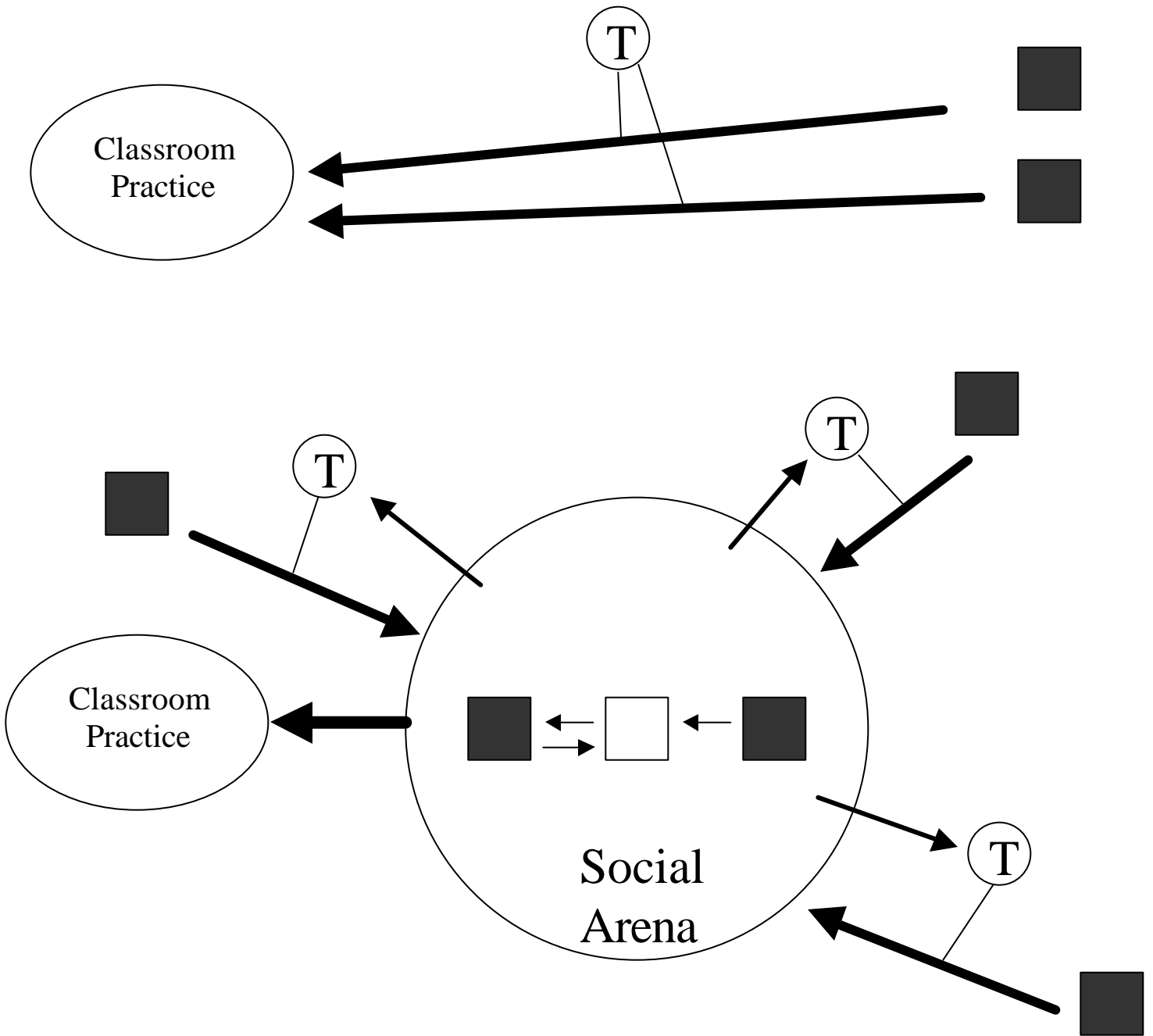
Teacher Support Team – Responsible for resources for teachers. This includes (a) Developing, publishing, and maintaining a recommended timetable for carrying out the bioassay protocol and/or exploration, (b) Constructing and/or modifying an inquiry-oriented lesson observation instrument (for use by student teachers and other teachers), (c) Determining needed supplies and assembling bioassay kits for all participating teachers (e.g., seeds, filter paper, deicers, instructions), and (d) Creating a framework for teacher pairing that assigns each student teacher a cohort partner, and guides their work in visiting each others' classrooms and evaluating their Inquiry Project implementations.

Nature of Science Team – Responsible for resources related to teaching and learning about the nature of science. This group will (a) Develop a web0based tutorial on peer review (we will give you a draft tutorial to work from), (b) Write and evaluate pretest/posttest items to gauge students' understanding about the nature of science, especially the role of peer review (these items will be incorporated into the instrument developed by the Student Team), (c) Prepare a paper instrument for student teachers that documents the implementation of the Inquiry Project in their classroom.

Appendix G – Preservice Project Participants

Inquiry Project	
Nate	Biology
Nancy	Agriculture
Emily	Earth Science
Darrin	Biology
Ian	Environmental Science
Sarah	Biology
Curriculum Development Course	
Meredith	Cognitive Psychology Senior
Lou	Agriculture Pre Student Teaching Teacher Education Student
Darrin	Biology Post Student Teaching Teacher Education Student
Sean	Biology Pre Student Teaching Teacher Education Student
Ruth	Agriculture Pre Student Teaching Teacher Education Student
Ellen	Microbiology Doctoral Student, Education Minor

Appendix H – Teacher Implementation

Classroom
Practice

T

Classroom
Practice

T

T

T

Social
Arena

Appendix H – Toxic Discussion

	Nancy	Emily	Darrin	Ian	Sarah	Multiple/Unknown
Okay, Um.						
One question I'd like to ask before we get started, is whether, we want to use,						
Well, it has to do with the wording.						
Like, toxic						
One pitfall we might have, is if we start asking, if we ask a question about toxic, or something about toxic, and the person doesn't know what toxic means, then, we get, nothing more than they don't know						
So, should we			Poison?			
use, say toxic, and, or poisonous, or should we, like						
Should we use both words, should we just use poison?						
	Should we say toxic ????					
				Poison and toxic, are, there's also a distinction, so we might also be creating a misconception, there, by associating them		

Or we could ask one question, what's the difference between being toxic and poisonous?		Toxic is supposed to be like it can kill you. Right?			
			What's the distinction between toxic?		
			I don't think I understand.		
I don't know ??					???
		I think toxic means its deadly, and poisonous doesn't.			
			No.		
I think toxic is scientifically defined					???
	Yeah		Yeah		
and poison is kinda, like a	and I think poisonous is very general				
literary term.	When I hear poison, I hear don't eat it				
	when I hear toxic, like, ?? large quatities.				
		Well I think toxic's worse		There's lots of toxins, I mean	
				There's toxic things, in, your carrots, if you, ??, if you, you have carrots	
				there's toxic in carrots, there's toxic in potatos	
				There natural toxins.	
	Cyanide in apple seeds				

I think scientists probably use the word toxic because its better defined and its not as much in natural speech, everyday speech, so					
	Do we have a dictionary?				
People say, something's poisonous, they can	???				
like, poison's a very used word		?? Probably ??? middle school kids.			
Um, and, like, its got lots of baggage					
Wereas, like you can say something, were, its got toxicity, but its very low, or something like that.					
But you cannot say, its, its poisonous, but very low!			??		
[laugh]	It's not very poisonous!				
It's not, too too poisonous.					
It's under the government acceptability for poisonous.					
[laugh]	[laugh]				
			Okay.		
But I think that, we should					
	Yeah		Poison might also be more, in reference to, consumable supstances, as opposed to toxicity being, you know, UV, or, rad, other kinds of radiation		

Right, you wouldn't say UV was a poison.					
			Right		
	??				
I think it's more of a literary, like, I mean, poisonous is more of that kind of					
Used in					
			Okay.		
			So what do you want to do with that, though?		
Uh, ??					
	I think		Do we define toxic, as the, as the		
	I think we should define toxic, because, what, I mean, if they don't know what the word toxic means, using poison isn't really a good substitute				
	We just established that its not a great substitute				
Yeah	Because we have problems with it, let alone them.				

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[i] In the gas laws example, this can easily be shown by looking at an advanced statistical mechanics textbook.

[ii] Or maybe it is. As stated in the introduction, my purpose is primarily to raise the question, rather than offer a definitive answer.

[iii] Not to be confused with Berger and Luckmann's (1966) "externalization".

[iv] While the parallel to Schwab's syntactical structures is less obvious than it was with substantive structures, we would argue the analogy still holds. By encompassing the rules of evidence, etc., syntactical structures refer to the means – devices, procedures, etc. - by which scientists *do* science. We are ascribing the same role to educational syntactical structures. The inclusion of Carlsen's (1991) notion of pragmatic structures may help here.

[v] According to Woolgar (1987), the innovators are the "insiders" who know the machine (technology).

[vi] Or in the equilibrium of *reinvention* as described by Bardini and Hovarth (1995).

[2] It's worthy to note that another EI teacher at Andy's school teaches the 10th grade applied section. Consequently, students in the applied program are exposed to both Andy's curriculum and the EI technology

[3] [T]he meanings attributed to an artifact by members of a social group play a crucial role in my description of technological development. The technological frame of that social group structures this attribution of meaning by providing, as it were, a grammar for it. This grammar is used in the interactions of members of that social group, thus resulting in a *shared* meaning attribution…The interactional nature of this concept is needed to account for the emergence and disappearance of technological frames (Bijker, 1098, p. 172-173).

[vii] The other option is a graduate course in curriculum theory and analysis.

[viii] Cornell's teacher education program certifies teachers in science, mathematics and agriculture. The teacher education students in the course were in these subjects. The elementary education student is in a separate program.

[ix] For example, Andy's classes were used for pilot testing and Nigel was actually spending a sabbatical leave on campus.

[x] This is presumably a reference to the Primary Investigator on the research project in which Ellen was involved.