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Examining Interpretive Studies of Science: A Meta-ethnography*

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Abstract

This paper aims to examine the interpretive studies of science. Meta-ethnography was employed along with some enhancement strategies supporting case collection, analysis, and synthesis. The study seeks to answer an overarching research question, "What are the descriptions of scientific practice as portrayed by ethnographic studies of science?" Three ethnographies of science were selected and analyzed. The results were organized along three elements: (1) overview of the ethnographic studies, (2) key descriptors, and (3) synthesis. It was found that the three interpretive studies of science had two converging themes: material culture and discursive activity. Each interpretive study revealed its distinct aspects of scientific practice. It was concluded that the material culture is the primary actant that shapes scientists' further activities, credibility and transformation of the community itself. The discursive activities inherent in scientific communities are a salient agency of doing scientific practice and the construction of scientific knowledge. Additionally, this paper highlights how the professional scientific laboratory is a system of literary inscription, the production of images, and reproduction of culture. This research into interpretive studies of science is to enrich our understanding of scientific practice and inform the potential audience to reconsider the practice of school science and its social structure.

Keywords: Meta-ethnography • Laboratory studies • Scientific practice • Science education

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Different fields of study examine science and its enterprise differently. Philosophers develop philosophical understandings of science in regard to the justification, methodology, and content (Hoyningen-Huene, 2006; Knorr-Cetina, 2001; Sismondo, 2010), whereas historians draw attention to scientific content and theories, and the development of historical artifacts (e.g., instruments) and ideas (Knorr-Cetina, 1995; Vinck, 2010). History and philosophy of science enrich our understanding of science along with a focus on experiments, but not on laboratories, which are natural sites for knowledge generation (Guggenheim, 2012; Knorr-Cetina, 2001). Sociologists have been interested in exploring the whole process of knowledge generation, the social structure of science, and the norms of scientific practice. Ethnographic studies have been conducted in many science-laboratory contexts (Duschl, 2008; Knorr-Cetina, 1995; Vinck, 2010).

Ethnographic studies in science are a means for further understanding the cultural portrait of professional science communities and examining the commonalities and differences of scientific practice that shed light on the common characteristics of scientific communities. In this paper, we draw on three exemplary ethnographic studies in the account of sociology of science: (*1*) "Laboratory Life: The Construction of Scientific Facts" (Latour & Woolgar, 1986), (*2*) "Beamtimes and Lifetimes: The World of High Energy Physicists" (Traweek, 1988), and (*3*) "Art and Artifact in Laboratory Science" (Lynch, 1985). To guide our investigation, we pose the overarching research question, "What are the descriptions of scientific practice as portrayed by ethnographic studies of science?" To answer this question, we analytically examine and document the concepts the authors used to represent and interpret the scientific practice and knowledge generation process. Next we make a synthesis of our documentation of the concepts the authors used. This investigation allows us to narrow the gap between school and professional science practice. This gap emerged from the misrepresentations of scientific work, or the way scientists perform their inquiries to conceptualize natural phenomena and a lack of understanding of the various dimensions of scientific practice.

Our purpose is not to criticize ethnographies of science within the context of any philosophical perspectives (e.g., relativism, realism, and logical positivism), but instead, to present the commonalities and differences among the three ethnographic studies, identify the distinct characteristics of scientific communities, and then portray a more holistic picture of how science is accomplished in order to translate them for use in understanding scientific practice in the science classroom. These three ethnographic studies can be conceived as past scientific communities, yet at the time, they have had groundbreaking impact in science and science education community. Their impact is still being observed in the field of science education. Therefore, being informed about the dimensions of past scientific communities can be a means for one to reconceptualize the dimensions of scientific practice in a way that reconsiders what the practice of science is and how it takes place in school science classrooms.

Theoretical Perspectives

Laboratory Studies: Different methodologies (e.g., ethnography and ethnomethodology) employed to understand the scientific and technological practices yielded laboratory studies (Knorr-Cetina, 1995). Laboratory studies are known as the anthropology of science and are associated with science and technology studies (STS). These studies explore the norms and characteristics of scientific practice and explain the constructive nature of knowledge production (Knorr-Cetina, 2001). In laboratory studies, sociologists, anthropologists, and ethnographers have conducted participant observations in research laboratories. These observations have augmented our understanding of science as practice and culture (Pickering, 1992; Ziman, 2000). The researchers of laboratory studies have highlighted the mutual relationship between the social world and the material world in the generation of scientific facts (Knorr-Cetina, 1999). Their observations along with a constructivist approach delineate the day-to-day practices of scientists, their social accomplishments, and the conceptual and practical culture of a research laboratory. Yet Lynch (1993) claimed these studies lack causal explanations, even though they provide a cultural framework for describing how scientific facts or cultural entities are created technically and construed symbolically and politically (Knorr-Cetina, 2001).

Historically, laboratory studies arose when sociologists, anthropologists, and ethnographers began to study science and technology in the early 1970's in order to directly observe the everyday activities of scientists and identify the knowledge-generation process. Some of these early ethnographies identified by Vinck (2010) include the following examples. The Belgian physicist and philosopher, George Thill studied a high-energy physics laboratory to describe the epistemic, organizational, and sociological dimensions of scientific practice in 1973. Gerard Lemaine and his colleagues analyzed a neurophysiology lab within the institutional and organizational contexts in 1977. In 1982, Terry Shinn examined physics, chemistry, and information technology laboratories. In the early 1980's, three concurrent and independent studies of laboratories in the state of California emerged. The French philosopher Bruno Latour and the sociologist Steve Woolgar performed a field study of a biochemistry lab entitled "Laboratory Life: The Construction of Scientific Facts." At the same time, the German sociologist, Karin Knorr-Cetina studied a biochemical laboratory using a constructivist perspective. She wrote "The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science" (Knorr-Cetina, 1981). She extended her analyses and later wrote "Epistemic Cultures" (Knorr-Cetina, 1999). In 1985, Michael Lynch published his ethnomethodologic study involving a neuroscience laboratory that addressed the social and practical accomplishments in situ of an order of knowledge. An American anthropologist, Sharon Traweek (1988) used symbolic anthropology to study two high-energy physics communities. Her ethnography explored and compared the cultures of laboratories in Japan and the US. In later years, the idea of the laboratory study along with the use of ethnography stimulated other researchers to be interested in technological practices in engineering (Bucciarelli, 1994; Vinck, 2003) and nanoscience technology (Fogelberg & Glimell, 2003). These were book-length ethnographies of science.

There have also been numerous ethnographic studies of science published in journal articles. Although these studies are not the focus of the present study, we briefly describe them in order to reveal that there have been studies investigating research laboratories within a sociocultural context and that this tradition is alive and well in contemporary research. For instance, Buxton (2001) examined a molecular biology research lab to discover the day-to-day practices of the lab members, their roles and relation with each other, their interests, and the features of the scientific community. She noted a status hierarchy among the lab members in regard to space allocation due to their education level and expertise. She concluded that the lab director's management style played a significant role in forming the social structure of the lab and establishing the work relations between the members. Likewise, Feldman, Divoll, and Rogan-Klyve (2009) investigated the identity transformation, membership, and reconfiguration of research groups when individuals were engaged in empirical research. They found that the identities of individuals were transformed from novice researcher to proficient technician, to knowledge producer. Throughout this transformation, the individuals gained skills and beliefs to continue scientific investigations and become members of a scientific community. They noted that research group leaders impacted the configuration and organization of their research groups and the social interactions among group members.

The above-mentioned studies conducted in research labs represent the social, cultural, and material dimensions of scientific practice (Buxton, 2001; Feldman et al., 2009; Knorr-Cetina, 1981; Latour & Woolgar, 1986; Lynch, 1985; Nersessian, 2005; Traweek, 1988). Yet, some researchers have been interested in exploring the cognitive accounts of knowledge-generation (Nersessian & Patton, 2009). Nersessian and her colleagues highlighted the reasoning and representational practices in problem solving within biomedical engineering laboratories. They contributed to our understanding of model-based reasoning, the problem solving process, and the repertoire (e.g., representation tools, forms of discourse, and activities) employed in creating and using knowledge. Moreover, they highlighted challenges researchers encountered, learning and development in the lab environment, and sense making and identity (Nersessian, 2005, 2006; Nersessian & Patton, 2009; Osbeck, Nersessian, Malone, & Newstetter, 2011).

Laboratory studies reveal the social and cultural characteristics of science and technology constructs (Bauchspies, Croissant, & Restivo, 2006). These highlight the social events scientists and engineers participate in their community, their communications and negotiations with other members, and interactions between human (*scientists*) and non-human agents (*inscriptions, machines or detectors*) throughout their daily activities (Sismondo, 2010). In addition, these studies help us conceptualize the organizational dimensions of a laboratory (Knorr-Cetina, 1995). In this view, a laboratory itself is a site for the manufacture of knowledge and a salient agency of scientific development (Knorr-Cetina, 1999). It is a site for persuasion and a system of fact construction (Latour & Woolgar, 1986). A laboratory is an evolving complex system that has epistemic, social, cultural, cognitive, and historical dimensions. Thus, laboratories are strategic sites for researchers to study and understand scientific work and organization (Owen-Smith, 2001).

The primary focus of this study is to understand how scientific practices are performed and accomplished in laboratory contexts, and to portray the diverse aspects of human activity in order to contribute to our understanding of science and its enterprise. However, there are other domains of science conducted in different contexts (e.g., outside of a laboratory and virtual laboratories). In this study, we do not intend to make generalizations of study findings for other domains of science. Instead, we want to conceptualize the role of a laboratory in the generation of scientific knowledge and the reproduction of the scientific community, which are characterized by the mutual relationship between human and non-human agents. Therefore, we will discuss our conceptualization of the laboratory in science classroom communities as we exemplify the different aspects of scientific practice emerged from the three exemplary ethnographic studies and the current science studies.

Method

Background

The goals of this study are to examine three ethnographic texts of science and compare the similarities and differences in each ethnographic text regarding how science is performed, as well as to make a synthesis of our findings in a way that contributes to our knowledge and understanding. We benefit from meta-ethnography as a research methodology (Noblit & Hare, 1988) along with some enhancement strategies (Doyle, 2003). Meta-ethnography is a mode of inquiry that lays a foundation for the synthesis of qualitative studies. It is a means for critically examining multiple cases, comparing them to make cross-case conclusions, and then relating them to one another in order to synthesize the interpretations of ethnographic studies (Britten et al., 2002; Doyle, 2003; Noblit & Hare, 1988). Meta-ethnography researchers use the interpretations and explanations from the original studies as data and translate them across these studies to produce a synthesis. Thus, meta-ethnography is interpretive rather than aggregative (Doyle, 2003; Noblit & Hare, 1988; Thorne et al., 2004).

Conducting Meta-ethnography

To conduct our meta-ethnographic study, we followed a seven-step process (Noblit & Hare, 1988) and applied some enhancement strategies that Doyle (2003) developed to boost the process of case selection, analysis, and synthesis. We started with the first step, *getting started* in which we identified an intellectual interest by asking, "How can we inform our intellectual interest by examining some ethnographic studies of science?" In Step 2, *deciding what is relevant to the initial interest,* we decided, to focus on interpretive studies of science to understand and represent scientific practice. A maximum of four ethnographies has been recommended to use for analysis in meta-ethnographic studies (Doyle, 1998, 2003; Noblit & Hare, 1988). In that regard, we applied boundary conditions for case requirements and unit of analysis in a way that enhances the process of case selection (Doyle, 2003). We established the criteria that each study had to include multiple data sources, be complete, have long duration and be book-length works, as well as have an impact on the science and technology studies literature. Ultimately, we selected a sample of the three published book ethnographies (Latour & Woolgar, 1986; Lynch, 1985; Traweek, 1988) providing an extensive amount of data to sufficiently address the research question. We will describe each of these studies in further detail in the next section when presenting the results of the meta-ethnography.

Step 3 involved the meticulous reading of the selected ethnographic texts to identify the main concepts. In this step, through repetitive reading studies, the first author recorded the details of each study, not limited to the study setting, participants, and methods used, including concepts, explanations, and interpretations addressed by the authors of the ethnographic case studies. Throughout his reading of the texts, he made an initial decision of how these studies are linked to each other, which is called Step 4, *determining how the studies are related* (Noblit & Hare, 1988). Then this fourth step allowed us to make a list of potential descriptors. Determining descriptors is an enhancement strategy for case analysis (Doyle, 2003).

In Step 5, Noblit and Hare (1988) propose *translating the studies into one another*, which implies comparing the concepts in one account with the concepts in the others. Yet it was unclear to us how to do this, therefore we started to extract key descriptors from each study to write individual descriptive narratives (translations) in the language of the original authors.

In step 6, *synthesizing translations*, Noblit and Hare (1988) suggest juxtaposing concepts (e.g., descriptors) and the translations of individual studies to develop a synthesis. We made close examination of three translations to write a final narrative. We followed the line of argument as strategy to establish comprehensibility in our synthesis (Doyle, 2003; Noblit & Hare, 1988). In Step 7, *expressing the synthesis* is where the meta-ethnography must be translated into the language of the intended audience. In that regard, we predict that the potential audience includes science education researchers, science teachers, and science-education policy makers. To communicate the final synthesis with them, we preferred rendering translations into their particular language.

Results

In this section, we present the results of our meta-ethnographic analysis. First, we begin with an overview of the studies included in the meta-ethnography to provide some information as the result of the repetitive reading of the authors' studies. Second, we identify key descriptors (e.g., concepts) from each case study and write descriptive narratives (e.g., translations), which would later allow us to make synthesis of the studies. Finally, we write a synthetic statement of the three studies together.

Overview of the Three Ethnographic Studies

First, Latour and Woolgar (1986) had been involved in the research laboratory at the Salk Institute. They were concerned with how the facts are constructed in a laboratory and how a sociologist can account for this construction. They studied "the work in which the daily activities of working scientists leads to the construction of scientific facts" (p. 40). They specifically answered several questions such as, "What are scientists doing?" "What are they talking about?" and "How are they constructing scientific knowledge?" in order to portray a culture of scientists in a neuroendocrinology laboratory. Latour and Woolgar, through their observations and interpretations, focused on how scientists integrated informal and formal writing in the construction of scientific knowledge, and how creativity and imagination played a role in performing science and the process of knowledge production. They concentrated on the role of inscription devices in the production and consumption of facts. They noted that scientists worked in competitive environments and challenged the work of their peers in terms of the reliability of their scientific claims and the inscription devices used. Persuasion was a means for resolving challenging arguments and/or claims made by others. They stated that "the result of the construction of a fact is that it appears unconstructed by anyone; the result of rhetorical persuasion in the agnostic field is that participants are convinced that they have not been convinced" (p. 240). Latour and Woolgar concluded the construction of facts as a long, gradual process of collective working to create order out of disorder. Second, Lynch (1985) conducted ethnomethodology in a neuroscience laboratory. He was concerned with the production of technical work and technical talk. He located his interest on the "social accomplishment of natural scientific order" (p. 1). To understand the account of technical talk and conduct in the lab environment, he investigated several topics (e.g., temporalization, practical continuity, tasks) on the social organization of lab inquiry. He looked at the temporal features of work performance, addressing the actual order to the performance of "method" rather than the schematic order of a "methods" recipe (p. 3). He noted that the laboratory's research was neither uniform nor did it have a coherent design, but rather there were a variety of projects, which characterized the laboratory environment. He investigated how scientists dealt with troublesome artifacts in electromicrographs. He noted that the observability of the phenomena depended on complex instruments or techniques for taking account of artifacts. He accounted for "troubles" or "artifacts" as an identifying feature of the local accomplishment of shop work. Thus, he demonstrated how artifacts were constituted and how scientists' distinction of facts from artifacts yielded the visibility of laboratory work. He also put a focus on how scientists resolved their disagreements in their conversations and how these disagreements were transformed into agreements.

Last, Traweek (1988) conducted her fieldwork at three laboratories, primarily at the Stanford Linear Accelerator Center (SLAC) and also at Japan's KEK (Ko-Enerugie butsurigaku Kenkyusho) facility and Fermilab in Illinois. She examined the community life of the particle physicists, how their community emerged and evolved, how (male) physicists were made and reproduced, and how knowledge was constructed within the norms of the community of physicists, for example, the ability to distinguish "data" from "noise". She conceived of laboratory sites as rich with disorder. She stated, "I have discovered that most nonscientists think of labs as extremely clean, meticulously tidy places where people in immaculate white coats do their work with minute, precise movements, and that scientists work alone, in silence. High-energy physics laboratories are not like that" (p. 57). She pointed to hierarchy and male dominance among the physicists in the community in terms of the placement of graduate students, the evaluation of experiments, and access to equipment and facilities. She observed the role of the physicist network as a way for novices to connect with other particle physics community members. The network was essential for them to shape their careers in high-energy physics. She noted that "talk" was an essential notion in the particle physics community. Physicists had to engage in discursive practices to negotiate time and lab resources as well as to distinguish data from noise. Through talk, physicists could evaluate the work of their peers and persuade their colleagues to support their work and sustain their membership in the community. She drew attention to the role of the construction of research equipment or devices (e.g., machines or detectors) in cultivating successful physicists as well as in the process of knowledge production. According to Traweek, without these devices the particle physics community would neither exist nor evolve.

Key Descriptors

Investigations across the three studies resulted in key descriptors that allowed us to make translations and later a synthesis (Doyle, 2003). In this section, we present and translate the key descriptors in the case studies, Latour and Woolgar's *Laboratory Life*, Lynch's *Art and Artifact in Laboratory Science*, and Traweek's *Beamtimes and Lifetimes*, respectively.

Latour and Woolgar (1986) used six key descriptors to interpret how science is practiced. These descriptors are *construction*, *agonistic*, *materialization/reification*, *credibility*, *circumstances*, and *noise*. The slow, practical work of the laboratory is the construction of a fact through transforming a statement into an object, or a fact into an artifact. In other words, the process of fact construction is characterized by the stabilization of a statement where all references are included to persuade statements or claims. In the "agnostic field" (p. 237), many characteristics of social conflict (e.g., disputes, forces, and alliances) and epistemological explanations of phenomena (e.g., proof, fact, and validity) are operationalized by scientists through the micro-processes of negotiation which take place regularly in the context of the laboratory. That is, scientists perform operations on statements such as adding or withdrawing modalities, and proposing new combinations. Their operations result in a demodalized statement, which is considered to be a fact. A fact can then take the shape of an object or equipment (e.g., artifact) a few years later. For example, inscription devices can be derived from "the reification of theories and practices" or "a well-established body of knowledge" (p. 68). Thus, "one cannot take for granted the difference between 'material' equipment and the 'intellectual' components of laboratory activity" (p. 238). Materialization or reification refers to the process of material considerations as a component of the thought process in science. "Once a statement stabilizes in the agnostic field, it is reified and becomes part of the tacit skills or material equipment of another laboratory," (p. 238). Incorporation of the intellectual components of laboratory activity into equipment allows scientists to obtain new, better inscription devices producing inscriptions and statements. This process provides them with the opportunity to gain credit to do science and reinvest credibility to make a move in the scientific field via "cycles of credit" (p. 201). Fact constructors deny that credit as reward is their motivation. Credit as reward cannot reflect the main purpose of their practicing science. In that regard, a working scientist does not ask, "Did I repay my debt in the form of recognition because of the good paper he wrote?", but asks "Is he reliable enough to be believed? Can I trust him or his claim? Is he going to provide me with hard facts?"(p. 202). The practice of science and its products are "entirely fabricated out of circumstance" (p. 239). Eliminating circumstances from statements determines the construction of a fact. That is, when scientists performed operations on statements to be transformed into a fact, reality was distinguished from local circumstances. It is then concluded that "if reality is the consequence rather than the cause of this construction, this means that a scientist's activity is directed not toward 'reality' but toward these operations on statements" in the agnostic field (p. 237). Investors of credibility consider their works' ability as to whether they can convince their colleagues that the data is different from the background noise produced in the laboratory. When a statement is transformed into a fact as a result of persuasion, efficacy of facts is evaluated and examined within that network or by "a set of positions" of scientific practice (p. 107). Otherwise, the data would not be warranted as reliable.

Lynch (1985) addressed a variety of descriptors to delineate aspects of *in situ* scientific work, such as *temporalization*, *projects*, *artifacts*, *agreements*, and *modifications of objects*. Temporalization refers to "the production of extended courses of inquiry in lab work through the serial ordering of tasks in the immediacy of an organizational setting" (p. 53). Lynch glosses temporalization of practices as ongoing and developing achievements rather than as the finished sequential products of projects of shop work. Projects are treated as sequential units of interest in the production of lab inquiries and essential features of laboratory shop work. A project encompasses sequentially arranged steps or "tasks." These are "irreducible procedural elements of projects," but "transferable across different projects" (p. 66). A project as an analytical unit in the temporalization of lab work is a contingent phenomenon shaped by the adequate performance of technical work in local circumstances. In other words, projects are bounded by the technical works of scientists, which have both definite beginning and end phases. This makes projects temporal phenomena in the social organization of lab work. Artifacts are part of ongoing projects. They are the results of procedural excesses (for example, "intrusions" and "distortions" that appear in natural phenomena) as well as the results of procedural inefficacies (for example, superstitions and the fallibility of procedures). The observability of artifacts depends on experimental procedure or the instrument. For instance, electron microscopic photography makes invisible natural entities visible. Artifacts are not collected and analyzed, but emerge as "troubles" in the lab work. Artifacts are not certain "things," but are possibilities related to absences in an observation rather than definite constructive presences, spots or blurs in a photograph (p. 86). When artifacts are identified, they are not considered as the accomplishment of local inquiry. Instead, they are found as "mistakes," "errors," "unfortunate developments," "problems," "hassles," "misleading appearances" or "equivocal interpretations" (p. 88). Lab members discuss the visibility of artifacts featured as indeterminate through assessments and agreements, and decide whether the material, for instance, a micrographic montage, can be used as data. Therefore, agreements are local occurrences in conversation where laboratory members make arguments over emerging problems, make plans to deal with it, and negotiate the reliability of data for the practical purpose of the local inquiry. That is to say, agreement among lab members is a substantial part of the way laboratory works are performed.

Lynch states that agreement is achieved through assertion, not through relating one utterance to another regardless of whether parties are telling "the truth," through agreement in their underlying attitudes or personal commitments (p. 189). Modifications in scientific accounts of objects are produced in the course of disagreement sequences. This process is eased through "achieved agreement" (p. 187) in a way that supports assertions and reassertions rather than reformulating them in scientific shop talk.

The main descriptors in Traweek's (1988) study are *construction, social organization, reproduction of physicists, masculine physics, noise, and time*. By construction, Traweek refers to building and re-building machines (e.g., detectors), which are at the heart of the particle physics community's contextual activities. These are the locations where "physicists and nature" as well as "knowledge and passion" (p. 17) converge. A detector is constructed to sensitively identify and measure undesired disturbances ("noise," p. 50), collect data promptly, distinguish noise, and effectively analyze data. Inventing detectors is a practice of physicists for discovering nature because detectors determine strategies for scientific research and research questions.

Building a new detector that effectively detects and records the traces of particles brings to a physicist "great honor" and "influence" (p. 49) in the community. A detector that perfectly functions at all times is shared with scientists in other fields until it becomes obsolete for high-energy physics. High energy physicists always look for new ways to collect complex data quickly so they engage in "designing, maintaining, and modifying" (p. 55) their detectors while simultaneously using it for their experiments. Different detectors designed to pursue a problem in any research group are mnemonic devices because detectors are viewed as the material embodiments of research groups and reveal that each research group has different modes of discovery and strategies to deal with noise in order to produce knowledge as well as to maintain the performance of good physics and a strong laboratory. Social organization is attributed to how a research group or the experimental particle physics community structures itself to continue to do lab work. The social organization of the laboratory associated with the history of a research group, its division of labor, and its strategy for discovering nature is shaped by building and rebuilding detectors. In other words, different detectors produce different research groups along with strategies for making research equipment and building a career in physics. Thus, detectors are considered the "signature" of any research group. The experimental particle physics community evolves by “training novices” (p. 74). Transformation of novices into expert physicists or a reproduction of physicists occurs through formal and informal education as well as through daily routines. Novices move from the textbook-based culture of undergraduate training into “the coherent ground state” in which graduate students learn “good taste,” “good judgment,” and “creative work,” and get the first “real feeling for physics” (p. 82). When they become young physicists, they live in the increasingly oral, competitive, and aggressive culture, meaning that they start shaping their reputation and endeavor to be inside the “old boys’ club,” which in turn reproduces individualistic, competitive, and insular (male) physicists. The routine transition of graduate students and post doctorates from one stage to the next is dependent upon relationships within networks. This transition allows them to be cognizant of the “hierarchy” (p. 93) and envision their final place in the particle physics community. Yet, this process encompasses anxiety and time, success and failure, as well as frustration and hope at each stage of the fifteen-year journey. Established physicists and full-fledged physicists even encounter circumstances that cause them to question whether they are still making a contribution to the community, or if their work is obsolete. The concept of time in the experimental particle physics community refers to the relation between “Beamtimes” (at the atomic scale which structures their study objects) and “Lifetime” (at the human scale which shapes their careers, their detectors, and their ideas). Beamtimes and lifetimes converge in detectors in which data is separated from noise and signals from nature are received. In turn, this constitutes a discovery. Building detectors, transforming novices, membership, and distinguishing data from noise characterize the practice of physicists and is shaped by the “evaluative and persuasive talk” (p. 118) inherent in high-energy physics culture.

Synthesis of the Three Ethnographic Studies

Our close examination of the three interpretive studies reveals that the practice of science in different research laboratories has two converging constructs: *material construct* and *discourse construct*. Material construct refers to the material culture that scientists generate and use to perform their contextual practices in research laboratories. This material culture is not limited to a list of instruments (e.g., inscription devices, machines, detectors), but also consists of inscriptions, statements, texts, and micrographs. The material culture is the primary actant that shapes the future activities of scientists, credibility, and transforms the community itself. At the same time, scientists as the primary actors design, build, and modify the material culture to reach to their goal. Thus, mutual relationships and dynamic interactions between actants (non-human agents) and actors (human agents) characterize the practice of science in research laboratories.

In the case of the scientists in Latour and Woolgar’s (1986) study, the products of inscription devices that technicians worked with were inscriptions, machine-generated texts that scientists treated as data and used to perform their operations on in the process of fact construction. Their authorship would be shaped and they would acquire credit, or credibility in light of the inscriptions (e.g., texts, graphs, or pictures) derived from these devices. A new, better inscription device could be yielded from the dynamic, mutual interactions between inscription devices, inscriptions, and the cognitive operations of scientists in the agnostic field. Scientists in Lynch’s (1985) study oriented their daily activities around dealing with potential troubles or artifacts. Troublesome artifacts were temporally emergent possibilities in electromicrographs or a photograph. Scientists were dependent upon instruments (e.g., an electron microscope) to provide the visibility of troublesome artifacts that resulted from procedural excesses and inefficacies. Identifying troublesome artifacts in the work of scientists did not determine their accomplishment; instead it led them to further discuss whether micrograph parts were usable, analyzable facts, and identify which parts artifacts were. Scientists negotiated to use microscopic montage excluding artifacts as data and determined the reliability of the data to accomplish their practical purposes. High-energy physicists in Traweek’s (1988) study met nature and brought their passion and knowledge together around machines (e.g., detectors). At the heart of the physics community were detectors that allowed physicists to distinguish noise and constitute a discovery. Detectors were the material embodiments, signatures, and representations of research groups because they were considered as mnemonic devices through which physicists would understand a research group’s history, its division of labor and the strategies taken to pursue a problem. High-energy physicists built and rebuilt detectors to continue their contextual practices because new, better detectors would allow them to collect complex data quickly and analyze effectively. At the same time, detectors allowed their community's evolution. Physicists established and sustained their community for the sake of detectors. Building new detectors was a way, a stimulus, for physicists to continue to make a contribution and avoid becoming obsolete in the community.

From the three studies, we synthesized the material culture as essential to the pursuit of scientific investigation. Scientists in these studies had different approaches to the machines (research instruments) in their work. On one hand, scientists in both the study of Latour and Woolgar (1986), and of Lynch (1985), trusted and credited the research instruments in their work as they produced inscriptions and micrographs resulting in scientific knowledge. On the other hand, scientists in Traweek's (1988) study built and rebuilt detectors to perform their practices. They considered them as mnemonic devices, and described how they designed, built, and modified them as practice of science \in addition to giving trust and credit to detectors. Discourse construct refers to discursive activities. These activities, we think, are related to "the rhetorical persuasion" (Latour & Woolgar, 1986), "shop talk" (Lynch, 1985), and "evaluative and persuasive talk" (Traweek, 1988). Discursive activities occurred when scientists in Latour and Woolgar's (1986) study obtained inscriptions, statements, or texts and engaged in transforming these statements into facts, which could be taken for granted, as well as distinguishing facts from artifacts. Their social endeavors to make statements about new information were iterative and interpretive in the sense that they performed operations of adding and withdrawing modalities on statements and formalized factual statements. In other words, the art of persuasion is the art of shifting statements from modalized positions to demodalized positions. However, their colleagues challenged the credibility and reliability of their inscription devices in addition to the efficacy of facts. They dealt with their claims and arguments through rhetorical maneuvers in the writing of scientific texts (e.g., scientific journal articles). Thus, the point of their discourse was apparently to establish facts. Scientists in Lynch's (1985) study performed their discursive activities to manage the transformation of a disagreement into an agreement. They utilized discursive activities in two ways: *talking about science* and *talking science*. On one hand, discursive activities in the account of talking about science were performed through lab tours and interviews with other colleagues. On the other hand, discursive activities in the account talking science occurred with their colleagues when scientists attempted to modify their interpretations of microscopic montages, their plans for an ongoing project, or their claims about the reliability of data. Discursive activities in the account of talking science were associated with descriptions, admissions of potential disagreements, and formulations of the original assertions, and challenging statements till photographs were taken as data. Scientific and technical discussions were oriented around efforts of clarifying and distinguishing facts from artifacts or troubles on the basis of visual clues (the analysis of discursive exchanges in conversations). Reaching agreements through discursive activities was shaped through social interactions and it was a way to contribute to the production of results. Hence, the point of shop talk was to construct a collective understanding of the natural phenomena they were studying. In Traweek's (1988) study, scientists performed their discursive activities associated with evaluative and persuasive talks. At the very moment of their work occurred discursive activities through oral communication rather than written communication. Talks were employed throughout designing, building, and modifying detectors. They were used to persuade their colleagues to support their work. Through these talks, the community of physicists determined who would access detectors, who would be allowed to try to build new detectors and construct facts, who would be a particle physicist, and what makes up a good detector. Thus, the point of these talks was to establish, access, and re-establish machines as well as to reproduce physics and its culture.

From the three studies, we conceptualized that talk is an essential agent for the practice of science and the process of generating knowledge. Although these three studies considered the role of discursive activities in science slightly different, talk was iterative, interpretive, persuasive, and evaluative at the very edge of doing scientific works. Thus, talk is a link to communicate with scientists, a tool to persuade their colleagues, a determinant key to construct a taken for granted fact, and a salient agent for transforming a community. More importantly, talk is inherent in the organization of a research laboratory.

Discussion

In the present study, we examined the three interpretive studies of science using meta-ethnography as a research methodology. The concepts that emerged in each case study were highlighted and translated for synthesis. The final synthesis was made for a potential audience who could understand, interpret, and reconceptualize the findings. The synthesis reflected two converging themes (material culture and discursive activities) among the three studies, though each case study individually had prolific aspects of scientific practice and the authors used different methodologies to understand the practice of science. Herein, we ground discussion on the laboratory itself and its importance in the selected ethnographies of science.

The laboratory is a system of literary inscriptions, the production of images, and the reproduction of a community. We elaborate these issues as the authors of these studies interpreted in their ethnographies. First, Latour and Woolgar (1986) described the laboratory in regard to the relation between office space and bench space. Yet, central to the laboratory is the office of the researcher, reader, and author. In other words, scientists perform activities such as coding, marking, altering, correcting, reading, and writing in their office. They juxtapose formal and informal writings with other artifacts (e.g., photocopies of articles, mail files, invoice books, lists of data) as well as with papers produced within the laboratory. Their activities in the laboratory result in the production of written documentations, data, and graphs. They construct their collective writings on the basis of output from inscription devices or texts by comparing and contrasting them with other articles in the published literature. Thus, they conceive of the laboratory as a house of writing activity.

Second, Lynch (1988) described the laboratory site as an environment for various technical specialties including particular instruments and facilities. These are distributed in the organization of the laboratory in regard to the ongoing projects. The laboratory is the site that hosts a variety of research topics along with special technical methods. These aspects of the laboratory support obtaining data from distinct research instruments through available technical approaches. Thus, the laboratory is a site of technical specialties, which characterize scientific work and produce natural objects (the material world) through laboratory research.

Latour and Woolgar's study and Lynch's study focused on the material aspect of the laboratory and account for the constructive character of the knowledge generation process, though social interactions and collective works also play a significant role. They focused on one knowledge area in one country and did not address the possibility of "the cultural diversity of knowledge" (Knorr-Cetina, 2001, p. 8235) as Traweek did in her anthropological study which addressed the cultural side of the laboratory and the technological side of physics communities. She compared and contrasted these research laboratories with regard to the social organization of the laboratory, detector design and construction, and leadership styles—all of which then characterized the community of physicists. For example, physicists in the U.S. laboratory used their detectors for a short while, whereas high-energy physicists in Japan designed and used durable detectors for their research purposes. In addition, the members in the SLAC community were always in contact with each other and shared their competence and resources to renew their next detectors. Since physicists in KEK worked at one detector and had less contact with others, they passed on durable detectors to the next generation.

The analysis of the three ethnographies of science reveals that a laboratory is not only a physical space where artifacts such as instruments and technologies are generated and utilized to continue to do scientific practice, but it is also a social organization of a group of people sharing a joint enterprise, interacting with each other, and actively engaging in their contextual practices. In other words, the laboratory is a setting where the material and social aspects of science are generated over time (Sims, 2005).

Implications for Science Education

This study addresses scientific practice as represented and portrayed in communities of science. It reflects the interpretive images of scientific practice employed in research laboratories, the processes that generate knowledge, and the reproduction of scientific communities. We use the reports of the interpretive studies of science to inform the potential audience of this study in a way that challenges the practice of school science and its social structure.

Professional science communities are grounded on the material culture that shapes and guides scientists' everyday activities. The material culture consists of research instruments and their development to continue to do science. The products of instruments are considered as data that play a significant role in generating knowledge, and the instruments themselves play a pivotal role in producing and reproducing the community of scientists. The material culture in research laboratories is not stable; instead, it is evolving as new technologies advance, communities renew, and scientists invest the credibility of their endeavors to generate knowledge (Nersessian, 2006). The material culture is dynamic and adaptive as scientists meet blocks on their way to reach a common goal. The investigations of scientists depend on temporally emergent goals and plans, and this temporality guides them to develop the material culture in order to continue knowledge-producing practices (Pickering, 1995).

In most school science-classroom communities, the practice of science is typically dependent upon teachers and textbooks. Students are provided with laboratory instruments to conduct school science investigations to apply and verify the knowledge presented by their teacher or from their textbook. The material culture they face in school science laboratory is stable (Roth, 1999). When new technologies appear in the industry, the curriculum makers force schools to purchase and use them, and then students are given them for doing their investigations. School science community's members particularly have the goals and plans that are memorizing and acquiring the knowledge taught, succeeding in exams, and being ready for the next year's concepts. A reasonable gap between the school science communities and the professional science communities with regard to the material culture emerges from this. To narrow this gap, a more realistic representation of scientific communities should be translated into school science classrooms. To do so, the potential audience of this study should adapt and translate perspectives, which have emerged from professional science communities. For example, they should encourage students to develop and pursue their own goals in a classroom community of practice (Ayar & Yalvac, 2010; Ayar, Aydeniz, & Yalvac, 2015). As mentioned in Apedoe and Ford's (2010) study, students should be motivated to build and re-build specially designed research instruments to collect data that relate to their research question. Data can be analyzed and argued among students about its reliability, and then they can generate meaning out of the data. In addition, students should be encouraged to develop their commitment to pursue their investigations and take ownership of their inquiries (Ayar et al., 2015).

Discursive activities in professional science communities are to generate scientific knowledge as well as to reproduce communities. The ability to obtain a taken for granted fact, to distinguish data from artifacts, and to evaluate the claims and findings depends on the discourse constructions within the community of scientists. Discursive activities determine the credibility and reliability of research instruments as well as the efficacy of facts. Their social endeavors to make a decision about the quality and reliability of microscopic images as data, for instance, depend on mutual negotiations as well as scientific and/or technical discussions. Discursive activities are both evaluative and persuasive. Communications among scientists guide and shape the next step for conducting their investigations. Interactions emerge in social networks through which scientists decide who will access to research instruments as well as for moving to the next stage in their academic career. Discourse constructions allow scientists to pursue their investigations, construct the social organization in the laboratory, and generate knowledge in communities.

In most school science communities, the everyday activities of students are not similar to those in professional science communities. School science discourse activities are confirmative and informative rather than evaluative and persuasive (Ayar et al., 2015; Chinn & Malhotra, 2002; Lemke, 1990). Communications are employed between students and their teacher in such a way that the teacher initiates a question, then a student responds and the teacher evaluates or provides feedback. Collective discourse constructions among students are rare compared to whole class discussions where the teacher dominates in the discourse of school science practices (Ozkal, Tekkaya, & Cakiroglu, 2009). Translating the scientific discourse of science communities into school science communities is a means for the potential audience of this study to revise the discourse practices in science classroom communities.

As portrayed in Traweek's anthropological study, the high-energy physics community is a complex and evolving system that hosts many individuals regardless of age, education, experience, and expertise. There is a status hierarchy among members of the high-energy physics community. She revealed that heterogeneity exists in the culture of high-energy physicists that includes novice physics students (e.g., undergraduates), doctoral students, postdocs, experts, full-fledged physicists, and so on. This in turn generates a social network among the members to move to the next stage in a community of physics. The physics community renews and reproduces itself, as novice physics researchers become experts over time. The training process contributes to this transition. There is an expectation that young physicists should contribute to the community by building new detectors and through knowledge generation. Nonetheless, in most school science classroom communities, there is a status hierarchy between teachers and students. They have differences in regard to knowledge, experience, and age. Such differences can be used to contribute to their research and learning. School science communities can develop a heterogeneity that includes students at different levels of knowledge and competence. To do so, its members should be encouraged to pursue an unknown and be given an opportunity to develop their own ideas and materials to perpetuate to do science. Heterogeneity in school science communities would be a stimulus for students and teachers to establish mutual interactions and transform novice students into more experienced ones. This cultural transformation process would contribute to the reproduction of school science community.

In professional science communities, laboratories are sites where both the material and social dimensions of scientific practice are dynamic. Therefore, in school science communities, laboratories should be dynamic in a way that allows teachers and students to generate their own material culture and reshape its social structure along with their goal and intentions. Although school science communities have a predefined goal to reach at the end of the academic year, the activities, roles, and responsibilities in school science communities should be restructured in a way that transcends curriculum objectives.

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