Paper presented at the 2000 annual meeting of the
American Education Research Association - New Orleans

LEARNING SCIENTIFIC PRACTICES IN THE ELECTRICAL TRADE: IMPLICATIONS FOR EDUCATION PROGRAMS

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ABSTRACT

An important feature of enculturation into a community of practice is the trajectory along which a newcomer progresses to become an old-timer schooled in the practices of the discipline. At different points along this trajectory different expectations of knowledge and proficiency are placed on the learner/newcomer. Insights valuable to science education practices were gained by conducting a two-year (and continuing) ethnographic study of a college-level electrical trades program in which both theoretical and practical science knowledge was an important element. This study consisted of two parts focusing respectively on a pre-apprenticeship college program, and on the subsequent apprenticing on job sites. An analysis of fieldnotes, interviews, and videotape/digital picture rendering of both college and work sites (collected as the first author engaged in an electrical trade apprenticeship) suggests that there are several discontinuities between science knowledge in the classroom and in the field site. Understanding these discontinuities, we can offer better science teaching in our classrooms. As well, evidence suggests that an increased technological orientation of the electrical trades (and others) requires an increased, more thorough, and more practical understanding of scientific principles ¾ which runs counter to many of the science programs aimed at non-university students in high schools.

CONTEXT

Becoming a participating member in a community that enacts specific practices entails more than simply acquiring knowledge about that domain. A “newcomer” is expected to acquire a body of facts participants ought to “know” and to develop competency in the tool-based practices pertinent to the domain. A third factor is the time-line along which entrance into the community of practice is articulated. In the process of going from “newcomer” to full member, different expectations of knowledge and proficiency are placed on the learner at different times.

At a time when lucrative areas of employment that traditionally required little schooling are reduced, adult members of those (now reduced) communities are faced with the need to reposition themselves as members of other, often more scientifically oriented, communities of practice. For instance, obtaining qualifications that have aspects of formal certification (such as being a journeyman electrician) opens up lucrative employment opportunities that twenty years as an (un-journeyed) electrician does not. The appropriation of scientific and technological practices in order to enter, as adults, a new community of practice poses unique problems. Scientifically and technologically oriented communities of practice, such as the electrical trade, have historically reproduced themselves through a process of apprenticeship. Some forms of trade apprenticeships involve working at the elbow of a single mentor—be it a Pueblo potter (Bunzel, 1929) or a Tugen blacksmith (Coy, 1992). Electrical apprenticeships in British Columbia, by contrast, entail periods of work in the field¾often at the employ of a number of firms over the four years of the apprenticeship¾and periods of training in an accredited college. Also, given the scientific rooting of electrical practices, the alternating periods of formal (college) and informal (field) training make electrical apprenticeships akin to the “scientific apprenticeships”(e.g., Traweek, 1988) currently at the center of investigation by a number of science educators. Central to any form of apprenticeship is the availability to the apprentice of a “zone of legitimate peripheral participation” (Lave and Wenger, 1990). Legitimate peripheral participation is understood as a role offered to the apprentice ¾allowing the apprentice to legitimately participate in the practices of the mentor, albeit peripherally, namely without being exposed to undue risks, and without being held unduly responsible for nefarious outcomes of the practice. Legitimate peripheral participation is also understood in terms of a geographical “zone,” defining an area in the physical proximity of a mentor. In this geographical zone, the apprentice can both witness trade practices being enacted, and be witnesses enacting trade practices. It is in this “zone” that the “newcomer's” knowledge and competency develop along a well-defined time-line (Lave & Wenger, 1991). In the past, traditional “newcomers” to electrical practice have been males in their early twenties. However, the current socio-economic restructuring has resulted in male and female adult members of declining communities of practice (such as forestry) attempting to enter the electrical trade, usually following government sponsored pre-apprenticeship courses.

Our research is concerned with understanding the nature scientific and technological practices, the appropriation of these practices, and the manner in which newcomers are accepted by experienced practitioners. As part of this research we have conducted long-term studies about knowing and learning in the electrical trade, both in formal (college) and informal (field) settings.

PURPOSE

This study aims to document the manner in which electrical trade practices are taught in college (as scientific and mathematically oriented activities) and in the field (as enacted practices) as part of an electrical trade apprenticeship. We also document the social dynamics of the educational process, particularly with respect to exchange of scientific notions. The study uses ethnography to document the teaching of scientific practices pertinent to the electrical trade and the unfolding of these practices in one pre-apprenticeship college program and in nine months of work in the field as an apprentice. Interviews with established members of the electrical trade in which they related their experiences in becoming members of the community of practice were also conducted. An analysis of the data was conducted to determine the nature of the cognitive and embodied skills required for accomplishing scientifically and technologically oriented tasks in the electrical trade.

THEORETICAL FRAME

This study was designed to investigate how learning scientific practices related to the electrical trade varies between formal (college) and informal (field) settings. Our research was informed by anthropological and ethnomethodological investigations of cognitive skills required in the completion of material activities (Brown & Duguid, 1992; Lave & Wenger, 1991; Roth, 1996). For our study of the reproduction of a community of scientific and technological practice we drew on the theoretical approaches and interpretive frameworks of other anthropological, ethnomethodological, and sociological studies of practitioners and apprentices at work (Coy, 1989; Latour & Woolgar, 1986; Lynch, 1985; Traweek, 1988). From this perspective, knowledge does not reside exclusively in people's heads; rather, it is decisively constituted by the way people go about their daily business. For example, knowledge is constituted by the way people justify what they do, the tools they use, the practices they adopt, and the stories they tell. Our approach also considers findings indicating that tool-related practices belong to a form of scientific knowledge that is extremely difficult to communicate, and that often has to be learned from an expert practitioner in the context of its use (Collins, 1982; McCain, 1991; Roth, 1996).

RESEARCH DESIGN

This study came about as part of the first author's retraining from a science and education background into a trade; the apprenticeship trajectory followed by R.R. to date is summarized in Table 1. Entrance into the trade through a college-based pre-apprenticeship program has become the route of choice for approximately half of the "newcomers" in the electricians' community of practice in British Columbia. Although no two apprenticeship trajectories are ever exactly identical ¾ in part due to the different nature of the employment secured by apprentices¾ the trajectory followed by R.R. is in keeping with trajectories followed by apprentices whose experiences were recorded in the field.

Ethnographic data collected during this time falls into the realm of auto-ethnography (see Hayano, 1982; Orr 1990), where the first author was in many ways "coming home" to a trade community, rather than investigating an "exotic other." As a teenager, R.R. had worked in the family business, assisting with the installation and maintenance of industrial laundry appliances, while more recently he had worked as a laborer and electrician's helper in the construction of single-family dwellings.

Table 1

R.R.’s Apprenticeship Trajectory to Date.

Freelance work as laborer and electrician's helper	4 months
Pre-apprenticeship Program, InterCity College	6 months
Job search	1 month
Electrical and sound system installation in a ten-plex movie theatre, working for Arrow Industrial Installations	5 months
Electric Metallic Conduit and cable tray installations, lighting, data, and fiber optic installations, working for Giga Power Installations	4 months

Our mode of data collection also falls into the realm of participant observation research, where the ethnographer is both observing and participating in the activity observed. However, unlike participant observation research conducted solely to gather data addressing a research question, R.R.’s ability to perform in the electrical trade¾ to secure work, to acquire skills, to attain progressively higher remuneration, and to successfully avoid electrocution¾ has very direct implications on his daily life. This sets our data gathering apart from simple auto-ethnographic participant observation, and into what we refer to as “Lived-Life ethnography.” This type of ethnographic work allows not only for the observation of the teaching and learning of scientific and technological practices, but also offers a profound experiential documentation of the stresses, hurdles, and initiations that accompany the transition from “newcomer” to full member of the electricians’ community of practice.

The ethnographic fieldnotes collected in this manner were further contextualized through interviews with established members of the electrical trade as they related their own experiences as apprentice. Interviews were videotaped and transcribed and, along with the ethnographic field notes, they constituted the data corpus. Interaction Analysis (Jordan & Henderson, 1995) was then used to analyze the data: members of the research team reviewed the videotapes, transcripts, and fieldnotes independently, building individual assertions about how scientifically- and technologically-oriented trade practices are learned, and what cognitive and enacted skills are involved. Individual assertions were debriefed in a group setting, each member defending their own interpretations. Tentative team assertions were reviewed in light of the data corpus, and were reformulated until they became representative of the data.

RESULTS

Our analysis of ethnographic data indicates that the conveying of scientific and technological practices occurs in radically different manners in the college and in the field. While the insular environment of the pre-employment program emphasizes the articulated versions of mathematics and physics, the field necessitates algorithmic, rapidly applicable, embodied form of these practices. The college program emphasizes understanding-based practices, while the field demands rapid use of algorithmic practices ¾ in keeping with the preliminary results our team reported last year (Racca, Roth & Bowen, 1999).

While it remains true that scientifically-based decisions about structural aspects of a project are becoming increasingly codified in blueprints produced by off-the-field “experts,” our data also indicates that imperfections and errors crawl into the experts’ artifacts. These errors need to be identified by the trades-persons before they are reified into massive, costly blunders at the construction site. In the teaching and usage of scientific practices, a second trend emerges in field settings. Although first- and second-year apprentices are encouraged to adopt algorithmic practices, third- and fourth-year electrical apprentices are expected to return to the use of understanding-based practices when scrutinizing blueprints before instructing a crew to go ahead with an installation. For example, in the installation of electric metallic conduit distribution networks, third- and fourth-year apprentices are expected to adapt the instructions in the blueprints to the reality of the obstacles encountered in running the installation as prescribed. Apprentices must be able to “scope out” appropriate routes around insurmountable obstacles *before* starting an installation, rather than colliding with said obstacles by following routes shown in the prints. Higher-year apprentices must also be able to document field changes made to the blueprints, and to produce a final print that shows the actual routes, called “as builts”, followed by the distribution network.

A tension arises, then, between the college and the field. This not only with respect to the emphasis on understanding-based practices versus algorithmic practices, but also as far as the value placed on “abstract knowledge” as represented by textbooks filled with mathematical formulae and by blueprints generated by off-the-field “experts.” In exploring this tension, our team chose to focus on the installations of electric metallic conduit distribution networks in a number of construction sites.

In the field, the value of blueprint-base routing of the installation is challenged by realities of the field. These challenges are often overlooked by off-the-field engineers who produced the blueprints: routes for the distribution network indicated on the blueprints often “crash” into large ventilation ducts, and sites of outlet boxes often prove to be located in areas undesirable to the network's end users (Racca, fieldnotes, 02/00.) Also, in the field the trigonometry-based approach to bending electric metallic conduit is challenged by the necessity for an algorithmic approach that generates runs of conduit in as safe and rapid a manner as possible. There is a stark contrast between the emphasis on “abstract knowledge” encountered by pre-apprenticeship students, and the field-smart, embodied kinesthetic knowledge used by electricians installing electric metallic conduit distribution networks in the field. We therefore chose the installation of electric metallic tubing distribution networks as an example of the difference in cognitive frameworks between the college and the field components of an electrical apprenticeship.

Setting the Scene: Apprenticing as an Electrician in British Columbia

Entrance into the electricians' community of practice in British Columbia is attained through a four-year apprenticeship. Typical time-lines for the apprenticeship are illustrated in Table 2.

The apprentice, the employer, and the Provincial Government enter a contractual agreement to ensure that the newcomer receive adequate field and college instruction to ultimately become a "Journeyman, M/F", the full member of the electricians' community. The timeline for the apprenticeship can be shortened by attending a pre-apprenticeship program, which is offered by the same community colleges that also provide the yearly training to apprentices. Completion of the pre-apprenticeship program is recognized as being equivalent to about half the field experience and all the college training gained by a first-year apprentice, as illustrated in Table 2.

The instructors of the pre-apprenticeship program attended by R.R. presented it as the best in the province. Pre-apprenticeship students at InterCity College operate in a self-paced, competency-based framework that is said to maximize the students' responsibility and to most closely mimic the learning that students will experience once in the field. The curriculum

Table 2

Time-lines for electrical apprenticeship in British Columbia.

Off-the-street route		Pre-apprenticeship program route	
"Newcomer" secures a job with an electrical firm, is indentured and works in the field	9 months		
Apprentice attends college for first year training	3 months	"Newcomer" takes Entry Level Training pre-apprenticeship training	6 months
Apprentice works in the field	9 months	Graduate secures a job with an electrical firm, is indentured and works in the field	9 months
Apprentice attends college for second year training	3 months	Apprentice attends college for second year training	3 months
Apprentice works in the field	9 months	Apprentice works in the field	9 months
Apprentice attends college for third year training	3 months	Apprentice attends college for third year training	3 months
Apprentice works in the field	9 months	Apprentice works in the field	9 months
Apprentice attends college for fourth year training	3 months	Apprentice attends college for fourth year training	3 months
Journeyman status		Apprentice works in the field	4 months

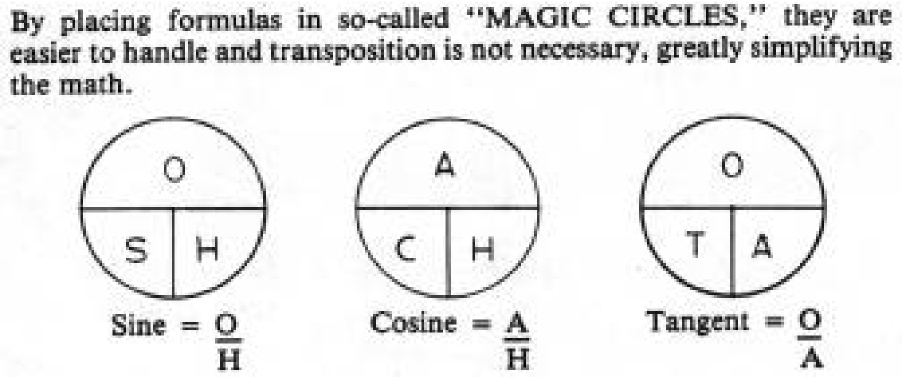
emphasizes “abstract knowledge” and within the first month of the program, students must master sections on solving mathematical problems (problems involving whole numbers, fractions, decimal fractions, ratios and proportions, percentages, powers and roots, graphs, and geometry) and sections on science concepts (properties of matter, thermodynamics, mechanical physics). These units lay the groundwork for later units on electromagnetism, circuit analysis, inductance and capacitance, diodes, and choice of conductors as a function of load and conductor length. These ‘scientific’ units are accompanied by hands-on activities aimed at having the student carry out observations and generate data that substantiate the formulae and theories presented in their study booklets. Along with the ‘scientific’ units, the curriculum is interspersed with more practically-oriented “shop” units, such as erecting scaffolds and ladders, using specialized power tools, cutting and threading rigid conduit (see Racca, Bowen & Roth, 1999) and bending electric metallic conduit. For all units, however practical in their nature, attention is paid to the theoretical framework behind the practice, rooting practices in the precepts offered by the likes of Newton, Boyle, and Ohm.

Of Distribution Networks: Cable Tray and Electric Metallic Conduit

Cable tray raceways and electric metallic conduit are used to set up physical distribution networks that will mechanically protect and support electrical distribution networks made of wires. A non-electrician can visualize the cable tray as a metallic ladder-like structure manufactured in 10-foot lengths onto which bundles of wires are rested. Electric metallic conduit can be visualized as chrome-colored metallic pipe through which wires are made to travel. The conduit is manufactured in 10-foot lengths (“sticks”), has a wall thickness of about 1/16 inch, and ranges in internal diameter from 1/2 inch to 6 inch. Large diameter conduit will “feed” metallic junction boxes (“JBs”) from which “runs” of smaller diameter conduit branch out to smaller JBs or to end-of-run “device boxes.” Using a biological analogy, a cable tray raceway can be thought of as a spinal cord, large-size electric metallic tubing as spinal nerves, junction boxes as ganglia, small-size electric metallic tubing as nerves, and device boxes as nerve endings.

“Code-ified” Practices: The Canadian Electrical Code on Distribution Networks

The Canadian Electrical Code describes the practices to be followed in accomplishing electrical installations that meet national standards for safety, mechanical stability, and electrical soundness. For cable tray raceways and electric metallic conduit, the Canadian Electrical Code specifies that they be “installed as a complete system,” entailing that all branches of the distribution network be made mechanically secure, and bonded together to a common link to ground. “Code” also regulates the distance and positioning of supports for cable tray and electric metallic conduit. The only guidelines provided by the Canadian Electrical Code as far as the transforming of linear lengths of tray and of conduit into three-dimensional distribution networks stipulate that the bends “shall be made so as not to injure the tubing or reduce its internal diameter,” and specify the minimum bend radii as a function of the type of conductors to be pulled through the conduit. The Canadian Electrical Code makes no other provisions as far as the bending of electric metallic conduit, or as far as the intelligent routing of cable tray¾ key elements to the successful installation of electric metallic conduit distribution networks.



By placing formulas in so-called "MAGIC CIRCLES," they are easier to handle and transposition is not necessary, greatly simplifying the math.

Sine = $\frac{O}{H}$ Cosine = $\frac{A}{H}$ Tangent = $\frac{O}{A}$

Figure 1: Magic circles (Cox, 1982).

Conduit Bending: the College Approach

The Entry-Level Training curriculum encompasses a unit on bending electric metallic conduit. In the framework of the self-paced, competency-based course, students are provided with written descriptions of the features of the piece of conduit they are to bend. They are also provided with "sticks" of conduit, benders, measuring tapes, protractors, and a textbook entitled *Electrician's Guide to Conduit Bending* (Cox, 1982). The text offers a mathematical method for determining the position and degree of each bend to be set in a conduit to give the conduit a desired trajectory. According to Cox, the method allows for the production of "conduit that you can step back and look at with pride, and the knowledge that it was bent right the first time" (Cox, 1982, p. iv). Cox provides a simplified rendition of trigonometry, illustrating the parts of a right triangle, and the relationships between an angle, its opposite side, its adjacent side, and the hypotenuse of the triangle. Trigonometric functions are presented in terms of "magic circles" which allow for solving for any one of the parameters involved in trigonometric ratios without using transposition (Figure 1). Covering the desired parameter with a finger yields the relationship between the other two parameters.

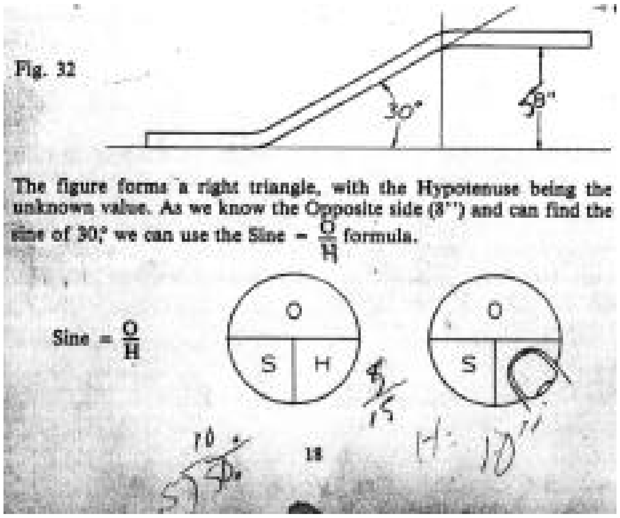


Fig. 32

The figure forms a right triangle, with the Hypotenuse being the unknown value. As we know the Opposite side (8") and can find the sine of 30°, we can use the Sine = $\frac{O}{H}$ formula.

Sine = $\frac{O}{H}$

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The procedure for accomplishing offset bends is explained in terms of the sine function relating the hypotenuse (namely the length of the pipe between the two bends) with the opposite side (namely the desired depth of the offset) and the angle of the bend. To achieve an offset of a given depth (opposite side), the student is instructed to use the sine function to solve for the hypotenuse (distance between bends) as a function of the chosen angle of bend (Figure 2).

A similar process is involved to determine the position of the first bend of an offset with respect to the leading edge of the obstacle to be surmounted (adjacent side). Here, the student is instructed to use the tangent function to solve for the adjacent side as a function of the angle and of the height of the obstacle (opposite side) (Figure 3).

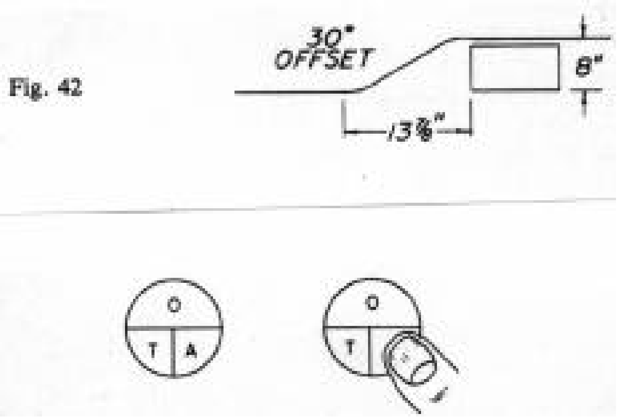

Figure 3. Using magic circles to calculate offset location (Cox, 1982, pp. 26, 27.)

The interpretive view of bending electric metallic conduit that one derives from the college teaching of the practice would see electricians carrying out extensive measurements and calculations to determine the angle and position of each of the bends they have to create. This would be followed by a one-time bending performance, yielding a perfectly bent conduit. Were anything to fail, the piece of electric metallic tubing would be discarded with no attempt at rectifying the bend and the entire operation would be repeated ¾ failure of the bend being probably ascribed to an error in either the measurements or the calculations. The time invested in performing a conduit installation would be immaterial, as the self-paced time-line of the pre-apprenticeship program does not entrain students to the strict time demands of the field. As we indicate in the next two sections, the practice of bending electric metallic conduit in the field looks radically different from the picture of it one would extract from the manner in which the practice is taught in college.

Field Practices: Distribution Networks in the Real World

Even armed with a copy of the Canadian Electrical Code, the pre-apprenticeship graduate is still ‘illiterate’ in regards to the real world rules and demands that govern the installation of cable tray raceways and of electric metallic conduit. The balance of the do’s and don’ts of installing electric metallic conduit distribution networks are summarized in Table 3. These are field-dictated rules that stem from the experiential knowledge of established electricians, and from the specific demands defined by a client. It must be noted that the degree to which these rules are applied is a function of a number of factors. First, some electrical companies, such as Giga Power Installations, set higher quality standards for themselves than other companies, Arrow Industrial Installations being one of the latter. Companies with high quality standards will stringently enforce rules dealing with the overall soundness and appearance of a conduit installation. Secondly, the presence and competence of the client and of the electrical inspectors involved in an installation affects the degree to which rules are enforced. Finally, the individual practitioner's personal standards affect enforcement of the rules described below. The synergy between personal standards and company philosophy often determines the length of employment of a given practitioner with a given company.

Table 3

Field-dictated rules that govern the installation of electric metallic conduit.

the **two-nineties** rule	the cumulative degree of bends between two pull points in a run of conduit should not exceed 180° (or two 90° bends)
the **no doglegs** rule	offset bends in a conduit must be perfectly aligned with each other so the conduit changes planes but not direction
the **shallow is mellow** rule	shallow angled offset bends should be used preferentially as they allow for ease of travel for the conductors to be pulled through the installed conduit
the **looks count** rule	exposed conduit must run in vertical or horizontal lines; conduit must run in uninterrupted segments that are as long as feasible, with a minimum number of couplings, and with identical offsets in parallel conduits
the **forgive or forget** rule	rather than giving up on a piece of poorly bent conduit ('forget'), use the conduit's resilience ('forgive') and field-learned 'tricks' to correct the bend

Conduit Bending: the Field Approach

Much as the Canadian Electrical Code rules hardly begin to describe the real world rules that govern cable tray and conduit installation, the trigonometry-based approach to conduit bending taught in the pre-apprenticeship program hardly provides the pre-apprenticeship graduate with adequate practices to effectively bend conduit in the field. The bulk of the apprentice's learning to bend conduit, then, occurs in the field. The traditional manner in which conduit bending is taught in the field is devoid of references to trigonometry, and is based largely on experiential notions. Calculations in the field are reduced to a minimum: in determining the position of the bends in an offset, a “multiplier” method is used. The distance between bends is determined by multiplying the desired depth of the offset by a “multiplier” specific to the chosen angle. Although the “multiplier” is in fact the cosecant of the angle, electricians in the field were not observed to employ the term “cosecant.” Similarly, our data show how an electrician would predetermine the position of an offset as a function of the distance from an obstacle (adjacent side) and the height of the obstacle (opposite side). However, this calculation was made using an angle-specific “location multiplier” that was not identified as the cotangent of the chosen angle for the offset. More often than not, location multipliers were not used; rather, the offset would be bent into a segment of pipe at a location chosen “by feel.” The offset would almost infallibly land in the desired position; exceptionally, a minor adjustment to the length of the conduit would be carried out.

Conduit bending in the field, then, is conveyed more in terms of experiential notions than in terms of mathematical formulae. Our fieldnotes point to four means by which these experiential notions are exchanged from journeyman to apprentice: a. direct instructions, b. stories, c. supervised experimentation, and d. witnessing exchanges of techniques between established practitioners.

a. Direct instructions: “Do me a 6” offset and use 30 degree bends.” Instructions in the field tend to be laconic at best: they contain the pertinent information to get the job done, but seldom provide any hints as to the reason for the chosen practice. Dispensing short instructions allow journeymen or senior apprentices to expedite their conduit installation by having the junior apprentices bend conduit for them. In turn they provide novice conduit benders with the chance to repeatedly enact the practice to be learned.

b. Stories: The direct instructions described above are often corroborated with stories pertaining to the practice involved. A “story” as “theory lesson” is exemplified below:

> When I was apprenticing I was working with this guy who put in a 60 degree offset to get around a 6” pillar, and when we had to pull the wires in they wouldn’t go through ‘cause the two 60’s back to back were too tight. And the silly bastard had me take the whole pipe down like I was the one who fucked up.

Journeymen usually tell stories to their apprentices during breaks in the task where the short instructions were handed out, contextualizing and explaining the direct instructions. In the example above, the apprentice was first instructed to bend an offset using two 30-degree bends. Later the apprentice was given a reason for the choice, albeit in the form of an anecdote: the shallower the bends, the greater the ease with which wire can be pulled through the conduit. It is worth noting that journeyed electricians recognize neither short instructions nor the stories as pedagogical tools: they are seen rather as means to get the apprentice to quickly accomplish simple bending tasks to speed up the journeyman's own work.

c. Supervised experimentation: Here a journeyman assigns the apprentice a bending task by illustrating where in a room the conduit must travel, and then leaving the apprentice to figure out how to accomplish the task. This method usually develops once the apprentice has been bending pipe under direct instructions for a while (two weeks to a month usually, depending on the brightness of both apprentice and journeyman) and has received various “theory lessons” in the form of stories. Depending on personal style, the journeyman may stop by the room periodically and nod or grunt, but it is largely the responsibility of the apprentice to ask questions or fetch help as needed. R.R. notes:

> I’m on the decking in theatre five: I’m standing on sheets of 3/4” plywood atop a three-story high scaffold. Peter has left me to run half-inch pipe along the joists, then down to the hallway ceiling height by way of an offset bend. I install the pipe on the joists, and before putting in the offsets I ask Pete what angle to use. Peter replies,
>
> Ideally you want to use 22-degree bends, because they are the easiest to pull wire through. But the multiplier for those bends* is hard to remember and hard to multiply by. Also, when you put in 22-degree bends, you have to look at the markings on the bender to see when you’re there. When you work on scaffolding, three floors up, you don’t want to be bending down to check your markings. What you want to use are 30-degree bends: the multiplier is 2, so you double the depth of the offset, and you have the distance to mark between the bends. And when the handle of the bender is straight up and down, the bend is 30 degrees, and you don’t have to check the markings. 22’s would be nice, 30’s are easiest, and never put in 45’s: they’re hell to pull wires through (Racca, fieldnotes, 07/99).* [2.6695, the cosecant of 22 degrees]

d. Witnessing the exchange of techniques between established practitioners. As seen above, attending to the following steps can attain an offset. First, one establishes the desired angle. Second, one marks the position of the first bend. Third, one establishes the position of the second bend by multiplying the desired depth of the offset by a multiplier (either memorized or retrieved from a “cheat sheet”, but not recognized as the cosecant of the chosen angle.) Finally, one marks the position of the second bend, and bends the conduit at the two positions. A second technique calls for the bending of the first bend to an arbitrary angle, followed by laying the “unbent” segment of pipe along the foot of a wall. Measuring the distance between the wall and the inside surface of the pipe, orthogonal to the wall, until the location is found where the desired depth of the offset is registered completes the operation. The conduit is then marked at that position, and the second bend is bent at that position until the pre-offset and post-offset segments are parallel. R.R. witnessed the exchange of these methods between a fourth-year apprentice and a journeyman, each of whom was initially only aware of one technique. The former was thrilled with finding out a “more precise” way to accomplish an offset using multipliers, while the second was glad to find a computation-free way of doing offsets “for when I’m too hung over to do math” (Racca, fieldnotes, 02/00).

DISCUSSION

Our data points to a difference in emphasis on scientific practices between the college component (pre-employment program and yearly ten-week courses for apprentices) and the field component of an electrical apprenticeship. As documented, the college component emphasizes understanding-based scientific practices, such as the use of trigonometry to work out angles for bending electric metallic conduits. In contrast, the field component of the apprenticeship emphasizes the fast, repeatable application of algorithmic practices. This creates an imbalance in the perceived value of scientific rigor between the college component and the field component of an electrical apprenticeship, and results in a palpable tension between college and field. Our data about the installation of electric metallic conduit distribution networks illustrates three main reasons for this tension: a. anachronism between college curriculum and field practices, b. lack of field contextualization of the college curriculum, and c. diverging interests between college and field.

a. Anachronism between college curriculum and field practices: the college still insists on teaching understanding-based mathematical practices with respect to bending conduit. These practices were of greater relevance to electricians in the era of rigid conduit, a type of metallic conduit similar to the “thin-wall” electric metallic conduit, but heavier and thicker-walled. Rigid conduit requires terminating by way of a rather complex three-step process ¾ cutting, reaming, and threading¾ we described in detail in an earlier article (Racca, Roth & Bowen, 1999). Coupling adjacent segments of rigid conduit is attained through threaded fittings, which offer minimal play and demand a high degree of precision in the manufactured conduit. Terminating rigid conduit can only be accomplished *before* the conduit is bent, requiring the electrician to pre-calculate the final length of the conduit, determining mathematically how the individual bends for an offset or a saddle will affect the final length of the conduit. With the advent of electric metallic conduit ¾ lighter, cheaper, and easier to bend and terminate ¾ the use of rigid conduit has been largely relegated to explosion-proof industrial installations (gas stations, oil refineries, petrochemical plants). The introduction of this new technology has resulted in the decreased need for precise mathematical prediction of the path and length of a piece of conduit. Electricians in the field have adopted the rapid algorithms of bending conduit summarized in Table 3. They know that final lengths can be adjusted by trimming the conduit with a hacksaw if it is too long, or by increasing the length of the conduit by “cheating” on nearby fittings, inserting less than the recommended amount of conduit into the slide-in fittings. However, the pre-apprenticeship curriculum at the college still demands that students be taught the trigonometric formulae that once dictated the bending of rigid conduit ¾ understanding-based mathematical practices that have been supplanted by algorithmic shortcuts made possible by the more “forgiving” technology of electric metallic conduit. Borrowing the imagery suggested by Peddiwell (1939) this appears to be another incident of teaching paleolythic students how to club miniature horses in a world where miniature horses have disappeared.

b. Lack of field contextualization of the college curriculum: the teaching of trigonometry as the route to precise conduit bending reflects the wider view the college has of itself as the place where the scientific building blocks of the electrical trade are taught. Although not contextualized in field-informed algorithmic practices, the mathematical and scientific notions behind electrical work are still at the core of the curriculum of the pre-apprenticeship course and of the yearly apprenticeship training. Students struggle to contextualize the science they are taught, but are offered no opportunity to do so within the spectrum of the college courses they take. The college defers to the field the contextualizing of scientific and mathematical notions, but the field, in turn, resorts to algorithmic practices to effectively circumvent the need for the application of college-taught material. The enactment of mathematical and scientific practices is deferred by the field to off-the-field "experts" in the form of electrical engineers that design the blueprints and dictate the materials to be used for a given application. Thus, the issue of relevance of the college-taught material is continually called into question by students in both the pre-apprenticeship program and in the yearly apprentice training courses. R.R. documents second- and third-year apprentices in the field describing their training at the college as a form of "putting in time" in order to keep progressing along their apprenticeship, and as "a holiday away from the field" (Racca, fieldnotes, 07/99). At no time were electricians in the field observed to describe their practices in terms of the scientific notions they were taught in college.

c. Diverging interests between college and field: along with the impact of evolving technology and the lack of contextualization of college curriculum, diverging interests between college and field contribute to the schism between these two settings of the apprentices' learning. The college is to be understood as the visible end of a much wider infrastructure of political interests, of trends in curriculum design, and of private sector interests. We refer to this conglomerate as the "educational corporation" ¾ composed in British Columbia of the Provincial Government, the Institute for Curriculum Transfer and Technology, the Industry Training and Apprenticeship Commission, and the college itself. The college, as visible interface for the "educational corporation", presents itself in terms of scientific rigor and of abstract knowledge. R.R. documents a senior instructor at InterCity College proudly stating that the pre-apprenticeship program may contain "shop activities", but that the later college components of the apprenticeship training have "labs, like in Chemistry or Physics." On asking the instructor where he might get more information on the mathematics behind bending conduit, R.R. was told that "you get to learn bending in the field, it won't come up again in second, third or fourth year" (Racca, fieldnotes, 03/00). The trend that emerged from this and other interviews with instructors is that the college almost reluctantly engages in "shop activities" while training pre-apprenticeship students, but finds its desired identity in the imparting of scientific "abstract knowledge" to apprentices that return from the field year after year. The trend towards designing "field-free" curriculum has been taken one step further by the Provincial Government this year, with the introduction of study modules for the apprentices which no longer contain specific laboratory activities. The offering of labs to reinforce the "abstract knowledge" packed in the study modules has been made the choice of individual colleges throughout the province, further removing the contextualization of the scientific concepts from the governmentally designed curriculum. In a manner similar to the conduct of large corporations (Orr, 1990; Orr, 1998), the “educational corporation” places its emphasis on the precepts of electrical work rather than on its practices. Within the educational corporation, formal descriptions of work and of learning are abstracted from actual practice. As aptly observed of the corporate world, “In a society that attaches particular value to 'abstract knowledge', the details of practice have come to be seen as nonessential, unimportant, and easily developed once the relevant abstractions have been grasped” (Brown & Duguid, 1992, p. 40). Once the electrical apprentice has moved beyond the pre-apprenticeship curriculum, the educational corporation entirely defers the teaching of work practices to the field. Within the educational corporation’s view of electrical apprenticeship in British Columbia there is little room for “learning-in-working”, or the fluid evolution of learning through practice. Furthermore, as stated by Brown and Duguid (1992) “Much conventional learning theory, including that implicit in most training courses, tends to endorse the valuation of abstract knowledge over actual practice and, as a result, to separate learning from working, and, more significantly, learners from workers” (p. 41). To the educational corporation, the electrical apprentice in the field is a “worker” who morphs into a “learner” once extracted from the field and placed in a college setting. Conversely, the field sees itself as a place where deadlines have to be met and clients have to be satisfied, rather than a place where a community of practice reproduces itself through the conscious handing down of embodied knowledge. Out of necessity, the field emphasizes the role of the apprentice as “worker” over that of the apprentice as “learner.” This leaves the apprentice in the field in danger of being seen purely as a worker by both the employer and the educational corporation. Allowing for learning through legitimate peripheral participation (Lave & Wenger, 1991) to take place on a job site, then, becomes the prerogative of the employer. As documented by R.R. while wiring of the ten-plex theatre, some employers view apprentices strictly as workers and will assign to them undesirable, repetitive tasks away from the zone of legitimate peripheral participation. These employers *de facto* deprive apprentices of the opportunity to observe the work of journeymen (a similar observation is reported by Marshall in Lave and Wenger, 1990, about apprentice butchers in U.S. supermarkets.)

In summary, anachronisms between what is taught in the college and what is needed in the field set up a first obstacle in the learning trajectory of an electrical apprentice. The problem is made worse by the lack of contextualization of the college curriculum in terms of field applications. Thirdly, the ongoing identification of the college as “the place where science is taught,” and of the field as “the place where jobs get done” fosters the perception of apprentices as “learners” when in college and as “workers” when in the field. This reinforces the tendency to design progressively more “field-free” curriculum for the college, and to divest the field of its responsibilities as a place of learning and of teaching. This results in the electrical apprentices having to navigate the process of scientific learning largely on their own in a context of conflicting expectations ¾ all this while trying to get through their college courses, and trying to keep their jobs in a fiercely competitive labor market.

IMPLICATIONS FOR SCIENCE EDUCATION

The scientific and technological nature of electrical work demand that a newcomer to the trade become proficient not only in the practices of the trade, but also in the theoretical frameworks behind the practices. As we discussed above, however, the apprenticeship structure currently in place in British Columbia falls short of this mandate in at least three areas: field pertinence of the college curriculum, field contextualization of the college curriculum, and achievement of synergy between college and field. A harmonization of the dialogue between field and college is at the center of our suggestions for the creation of a more effective apprenticeship to the electrical trade.

Issues of field pertinence of what is taught at the college can be addressed through the integration of exponents from the private sector in the design of college curriculum, bringing up-to-date technologies into the study modules and onto the shop floor. With a small investment in public relations at the hand of the Center for Curriculum Transfer and Technology, materials and trainers would easily be attained from the private sector. It is in the best interest of the private sector to generate practitioners that have already been made familiar with up-to-date technologies, thus avoiding the cost of later retraining.

Issues of field contextualization of the college curriculum can be addressed by a process of rediscovery of the educational corporation's own roots in the communities of practice it aims to educate. The implementation of intake and exit interviews to accompany the yearly apprentice training at the college would give curriculum designers a sense of what in the curriculum the apprentices recognize as pertinent and helpful in the field. Curriculum designer would also benefit from closer interaction with employers and technology suppliers in the private sector. These measures would contribute to the acquisition of a fresh perspective on content, curriculum, and assessment. This would lead to the designing of a college curriculum that is reflective of the realities of the field, and to the devising of field-informed, “authentic” problems, projects, and assessments on which to evaluate the apprentices' progress in college (Smith and Douglas, 1997).

Issues of lack of synergy between college and field can be addressed through a revision of the self-appointed identities of the college as “the place where learning happens” and of the field as “the place where jobs get done.” For their own reasons, both the field and the college have been removing apprentices from the zone of legitimate peripheral participation. In the field, employers are too busy trying to meet deadlines and bottom lines to offer apprentices the license to learn through legitimate peripheral participation. Employers routinely see apprentices as “workers”, sometimes deferring all forms of teaching to the college. The college in turn has embraced its corporate identity, offering apprentices the precepts rather than the practices of the trade. Admittedly, it would be impossible to mandate employers to offer apprentices broad exposure to the practices of the trade, and a sojourn in the zone of legitimate peripheral participation. It is, however, feasible to mandate the college to become a place for apprentices to experience the legitimate peripheral participation that is denied them by the field. The college curriculum would then be tailored around context-building outings to sites where different (and sometime infrequent) applications of theoretical notions are enacted. For example, a trip to a lumber mill would contextualize the use of large-scale capacitors to improve the power factor of a bank of motors better than calculations done by an instructor on a chalkboard. This trip would also situate the practice in personal experience and therefore be literally more “tangible” than a lab done by the apprentice with a decontextualized scale model of the practice.

In conclusion, our recommendations for the harmonization of the dialogue between the field and the college hinge on both of these settings surmounting issues of status. The field claims its status through the rejection of precept in favor of practice, while the college claims its status through the teaching of decontextualized precept in an environment isolated from practice. It is only through the mutual recognition that status is not lost through the integration of precept and practices that effective science teaching and science learning will find its way back into the electrical apprenticeship in British Columbia.

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