Apprentices and Gurus: Two Models of Modern Workplace Learning

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Abstract

The predominant model that researchers use to explain how newcomers learn in the workplace is apprenticeship, based on the centuries-old arrangement in which knowledge passes from a master to a novice. Traditionally, the apprenticeship model described how workers gained skills and knowledge. More recent versions call attention to how individuals assume new roles and identities within the workplace and the community of practice. In this paper, we explore the limitations of, and alternatives to, the apprenticeship model. We examined on-the-job learning in two engineering occupations: structural engineering and digital chip design. We found that a conventional apprenticeship model well characterized learning among structural engineers. A different model, which we termed a “guru” model, better described learning among chip designers. In both models, learning predominantly occurred via dyadic exchanges: Among structural engineers, these exchanges reflected a vertical organization of knowledge by which seniors taught juniors, but among chip designers they represented a distributed network of specialized knowledge in which all engineers taught and learned. Learning in both occupations was primarily about skills and technical knowledge, not roles and identities. Our findings challenge the universality of the apprenticeship model and the more recent trend towards framing all workplace learning as role socialization and identity transformation. Our findings thus provide a basis for reconceptualizing workplace learning in terms of how individuals learn new skills and knowledge at work rather than how they become insiders within the firm or old-timers within the community of practice. We discuss implications for theories of workplace learning and socialization.

Keywords: workplace learning, knowledge, skill acquisition
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INTRODUCTION

Throughout much of history, new workers learned their craft at the side of masters. Such learning arrangements were formalized during the Middle Ages in apprenticeship contracts that specified not only training and supervision, but also lodging, food, and clothing (Applebaum 1992). In a traditional apprenticeship, a master, experienced in the ways of work, taught an apprentice, a novice who began with little or no work-related knowledge. Knowledge flowed asymmetrically from the older master to the much younger apprentice in what was primarily an exclusively dyadic relationship. Each worker eventually came to obtain knowledge of all aspects of the work such that little specialization occurred within the occupation. Although the importance of formal apprenticeships has faded with time, this centuries-old arrangement for passing on the skills and secrets of work remains a predominant theoretical model for describing workplace learning despite considerable changes in the nature of work. In this paper, we investigate the limits of, and alternatives to, the apprenticeship model of learning in the modern workplace.

The Importance of Workplace Learning

Workplace learning has always been highly valued in certain occupations. Today, most formal apprenticeships are found among the craft and skilled trades, including carpenters, electricians, bricklayers, plumbers, boilermakers, and tool and die makers. Several characteristics of work in these occupations help explain why the workplace (rather than school) is considered the best place for learning and why apprenticeships are appropriate. In these lines of work, manual talent is considered as important, if not more important, than the cognitive abilities that are the focus of formal education (Barley 1996b). Materials and the worker’s
kinesthetic sense of them are integral to performance because vagaries in materials and situations often require on-the-spot problem solving and ingenuity (Barley 1996b, Orr 1996). Additionally, craft knowledge tends not to be specialized: there are not, for example, different kinds of boilermakers. As a result, a new worker eventually can attain mastery over the full set of occupational skills and can learn those skills from a single master. In sum, learning by doing under the guidance of a more experienced worker in the context of the work environment is understood within the craft and trade professions to be a good method for gaining skills and acquiring expertise.¹

Workplace learning also is important among many of the occupations that historically adopted university or college training as a prerequisite for entry into the field. In medicine, classroom instruction is followed by years of internship and residency in hospitals, where skills and knowledge are gained in the course of practice (Bosk 1979, Friedson 1970). Similarly, students in university teacher-credentialing programs are required to complete extensive student-teaching experiences in K-12 classrooms. To be licensed as a certified public accountant in California, one must have two to four years of accounting work experience in addition to possessing a bachelor’s degree (or taking a similar number of semester hours at a college or university) and passing a certification exam (California Board of Accountancy 2003). Apparently, members of these occupations recognize that formal education alone cannot provide all the knowledge and skills required in practice and that the workplace constitutes the appropriate environment for gaining the remainder.

¹ Working in craft and skilled trades may also require classroom instruction, but the hours devoted to this type of learning are far outnumbered by hours spent learning in the field. For example, a typical electrician’s apprenticeship requires 144 hours of classroom instruction and 8000 hours of on-the-job training (Bureau of Labor Statistics 2002).
In older professions like medicine and law, professional organizations introduced educational requirements in large measure to limit the size of – and control who was admitted to – the profession, thus preserving the economic welfare and status of their members (Larson 1977, Elliott, 1972). Yet, several characteristics of professional work hint at the benefits of classroom instruction beyond the calculated control of entry into the profession. Certain work situations are so rare that their occurrence during the period of apprenticeship cannot be guaranteed; for example, in medicine, rare diseases can be more reliably and routinely discussed in school than in the hospital (Becker 1972). Many professionals work in isolation and thus have little opportunity to learn the cultural values and norms of their profession except via collective formal training (Becker et al. 1961, Merton 1957). Perhaps the greatest advantage of classroom instruction is that it provides an efficient mechanism for students to acquire the specific body of foundational knowledge for their profession. The development of scientific medical knowledge in the 1800s certainly provided legitimacy for formal education requirements among physicians (Elliott 1972). Likewise, established bodies of knowledge in law, accounting, and engineering lend themselves to classroom instruction. Overall, both workplace learning and formal education appear instrumental in many professions. Carr-Saunders and Wilson (1933) suggested that formal instruction provides the opportunity for gaining theoretical knowledge while on-the-job training affords the acquisition of practical knowledge.

Granted, certain lines of work appear to place little emphasis on, or fail to acknowledge, the importance of workplace learning. In many disciplines within the physical and social sciences, business, and engineering, fresh university graduates are seemingly accepted as fully trained members of the occupation. A number of modern occupations fall into this set, such as computer scientists and programmers, aerospace engineers, human resources specialists, urban planners,
and economists. Yet, occupations that place little emphasis on workplace learning may severely underestimate its true role and importance. Frequent changes in the processes and practices of modern work, and in the technologies employed to carry it out, would seem to require most workers to learn new skills and knowledge throughout their careers.

Despite the importance of workplace learning and its ubiquity for a broad swath of the workforce, little research has investigated how workers acquire new skills and knowledge on the job – a significant error of omission. Workplace studies have focused instead on the socializing processes that shape individuals as they adopt new roles and identities upon entering the workplace, further drawing scholars’ attention away from the learning of skills and knowledge within an occupation. Consequently, the focus of the centuries-old apprenticeship model as applied in studies of workplace learning has shifted.

**Focus on Role Learning and Identity Formation**

Sociologists have long distinguished two types of learning in the workplace, one concerning the adoption of social identity associated with a given role and the other concerning the acquisition of technical skills and knowledge required in that role (Bosk 1979, Bucher and Stelling 1979, Olesen and Whittaker 1961, Carr-Saunders and Wilson 1933). Scholarly interest, however, has strongly favored learning about roles over learning about skills and knowledge. Hughes (1958: 119) reflected this interest when he noted, “Initiation into a new role is as much a part of medical training as is the learning of techniques; indeed part of it is to learn the techniques of playing the role well.” Van Maanen and Schein’s (1979) model of organizational socialization, which described how experienced workers shape the values, behaviors, and perspectives of newcomers, is representative of research that sought to depict how initiates to the workplace are transformed into insiders. As a result of such research, quite a bit more is known
about how individuals assume new identities than about how they learn the technical skills and knowledge of their occupation.

Van Maanen and Barley’s (1984) work on newcomers’ progression within occupational communities, which arguably might have considered skill and knowledge acquisition given the focus on occupations rather than organizations, provides another example of how role socialization and identity transformation dominate interest in workplace learning. Van Maanen and Barley (1984: 287) defined an occupational community as “a group of people who consider themselves to be engaged in the same sort of work; whose identity is drawn from the work; who share with one another a set of values, norms and perspectives that apply to but extend beyond work related matters; and whose social relationships meld work and leisure.” Building on Schein’s (1971) model of organizations, in which newcomers move through stages (e.g., proviso member, confederate, confidant) as they gain acceptance and become more central within a functional group, Van Maanen and Barley argued that neophytes move towards inclusion in the occupational community during an initial period of training and testing. Especially at the beginning of this transition, newcomers may be assigned “dirty work” to test their mettle or to socialize them to various aspects of the work. Newcomers are taught the “rules of the game” and their willingness to play by them is judged by more senior members (Van Maanen 1980). Workers who ultimately gain inclusion are identified as “sages,” “old hands” and “old timers.”

Van Maanen and Barley’s research provided a valuable model of an individual’s socialization and eventual inclusion into a group of individuals who perform similar work, but it ignored equally critical issues of how individuals gain the actual skills and knowledge necessary to perform that work. Understanding how individuals gain skills and knowledge is important for more than human resource concerns such as how to shape training programs, assign mentors, and
evaluate performance. More broadly, organizational theory stands to benefit from an understanding of how workers gain skills and knowledge because such acquisition is likely to be key in any process of workplace socialization. For example, powerful old-timers may purposely (or unintentionally) stall a newcomer’s progression by limiting the skills he acquires or reducing the pace by which he is allowed to gain new knowledge. Neophytes may fail at “the rules of the game” not because they fail to endorse and assume the norms and values of the occupational community, but rather because they simply cannot perform the tasks assigned to them. Individuals may leverage their increasing skills and knowledge to gain more central positions in social networks or to speed up their progression towards full inclusion in the occupational community or firm. Understanding how workers learn skills and knowledge at work is therefore instrumental in gaining an understanding of the social dynamics of the workplace.

Interestingly, scholars who limit their focus to identity transformation and role learning often equate the workplace socialization process with apprenticeship. As a result, the apprenticeship model has evolved from a specification of how individuals are expected to gain technical knowledge at work and progress through stages of skill mastery to a depiction of how initiates’ identities are shaped as they adopt new roles. This altered emphasis is evident in a series of studies of occupational training overseen by Blanche Geer and Howard S. Becker. The researchers’ interest in these studies lay in “individuals and groups in interaction,” which led naturally to examinations of how newcomers are socialized into the workplace (Geer 1972: 15). In one of these studies, Haas (1972, see also 1977) discussed how high steel ironworkers initiated neophytes through “binging” (taunting) to test and evaluate their self-control in an exceedingly dangerous environment. Notably, Haas focused on how experienced high steel
ironworkers came to accept neophytes as working peers, not on how new ironworkers learned to perform their tasks.

This shift in emphasis in the apprenticeship model is particularly pronounced in Lave and Wenger’s (1991) theory of situated learning. According to this theory, all learning is situated in activity and is an integral part of social practice and culture. In situated learning theory, Lave and Wenger challenged a basic premise of the standard view of apprenticeship: Rather than presuming that most learning occurs in primarily exclusively dyadic relationships, in which knowledge flows asymmetrically from the master to the novice via explicit teaching, Lave and Wenger argued that learning occurs naturally and inevitably in the course of participation in the activities of a community of practice.²

According to Wenger (1998), a community of practice consists of individuals who are engaged in a joint enterprise and who share a repertoire of stories, tools, artifacts, events, and concepts. Situated learning theory’s focus on the community of practice admits a much richer array of relationships than the master-novice dyads that characterize conventional notions of apprenticeship. In this theory, learning is construed as the process by which a newcomer becomes an old-timer within a community of practice. The construction of one’s identity as an old-timer subsumes and motivates the (less important) acquisition of particular skills or performance capabilities. This idea is central to the transformation of apprenticeship as traditionally conceived.

Many of the ideas that comprise situated learning theory are reflected in earlier work.³ By incorporating them into a single theory, Lave and Wenger have provided a unified and useful

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² Although Lave and Wenger allow that many forms of situated learning exist, the only form that they expound upon is apprenticeship, a limitation of their work to which we shall return.
³ See Van Maanen and Barley (1984), Bucher and Stelling (1977), and Hughes (1958) for discussion of occupational communities, colleague groups and colleague networks as comparisons to the concept of a community.
framework for thinking about learning at work. Yet, like much of the research on role
socialization in the workplace, situated learning theory’s heavy emphasis on social identity
transformation runs the risk of paying too little attention to skill and knowledge acquisition.
With its focus on the adoption of identities through participation in the community of practice,
situated learning theory implicitly invalidates a question of utmost importance: how does a
person learn the skills of, say, butchering, and replaces it with: how does a person learn to
become a butcher? Situated learning theory acknowledges that acquiring skills is a component
of the transformation from newcomer to old-timer, but it makes no effort to elucidate the
mechanisms and processes by which skills and knowledge are acquired as part of the larger
learning process.⁴

The de-emphasizing of technical skill and knowledge acquisition across this literature
constitutes a critical limitation because even in craft occupations, acquiring skills, or learning
what Sudnow (1978) called “ways of the hand,” is hardly a trivial matter. Moreover, in much
modern technical and knowledge work, advances in technology, materials, processes and
equipment may render existing technical skills and knowledge obsolete. Modern workers might

⁴ Arguably, situated learning theory, and past research on workplace learning more generally, could overcome
this limitation by incorporating an existing model of skill acquisition (e.g., Dreyfus and Dreyfus 1986). Integrating
such models, however, is difficult. Existing skill acquisition models generally view the movement from novice to
expert as a linear progression. This formulation is problematic in many workplace contexts for several reasons.
First, it is not always the case that novice equates to newcomer and expert equates to old-timer. A machinist in a
cross-training program, for example, may be new at learning how to operate certain equipment despite having been
on the job (as an accepted and fully participating member of the workplace) for many years. Likewise, a newly
hired college graduate may already be an expert software programmer on the basis of her long years of computer
hacking. Second, equating time on the job with acquired expertise is made difficult in part because the unit of
analysis in skill acquisition models is a single skill rather than the totality of skilled occupational performance. The
focus on how skills are developed independently is too narrow for examining how an individual learns multiple
skills, some simultaneously and often at different rates. An initiate to a consulting firm, for example, may learn in
the course of her first assignment how to maintain billing records, conduct analyses, and prepare reports. Her
learning on one task might aid her learning on a related task. Finally, the whole of mastery of an occupation may be
greater than, or at least different from, the sum of expertise across the occupation’s component skills. Occupational
mastery may entail connecting and integrating skills and knowledge into a conceptual whole (Bransford, Brown, and
Cocking 1999).
experience multiple cycles of technological obsolescence in the course of their careers. To function well in these environments, workers need to acquire new technical skills and knowledge frequently. Unfortunately, these kinds of work have been largely absent among past studies of workplace learning. As a result, researchers have missed opportunities that might have revealed the limitations of theories and models that place little emphasis on skill acquisition.

**Learning in the Modern Workplace**

Failing to pay attention to how technical skills and knowledge are acquired not only constitutes a critical gap in past research, but it may have engendered a second major limitation, namely the restriction of attention to only one form of learning: apprenticeship. Although Lave and Wenger allowed that multiple forms of learning may exist, their work demonstrated the application of situated learning theory only to apprenticeship, thus leaving the theory and its implications unarticulated for non-apprenticeship forms of learning. Others studies of workplace learning similarly have not yielded alternative models.

Apprenticeship as the singular model of workplace learning is likely to fall short of describing and explaining how modern workers gain skills and knowledge on the job for at least three reasons. First, apprenticeship is likely to be ineffective in fields where the knowledge required to perform work changes rapidly. Triggered, for example, by changes in the tools and technologies employed at work, rapidly changing occupational knowledge should decrease the potential for “old hands” to teach new ones. Moreover, rapid change may entail considerable learning on the part of all individuals in the workplace, not just the recent entrants, whose learning, alone, stands at the heart of the apprenticeship model. Second, the master-novice dyadic relationship may be inadequate in occupations where knowledge is specialized. Here, new workers may need to study under several individuals to gain sufficient fundamental
knowledge. Third, in occupations where practical training follows formal education, the apprenticeship model’s assumption that the novice has no or little work-related knowledge is invalid. When viewed in light of changes in the nature of work over the past half century, including the rise of professional and technical work (National Research Council 1999, Barley 1996a) and the transformation of many kinds of clerical and production work that followed the introduction of new control and information systems (Zuboff 1989), these reasons all point to the strong likelihood that alternate models of workplace learning would be more appropriate. It is instructive that each of these three reasons suggests that the nature of knowledge within an occupation is an important factor in determining its model of workplace learning.

Redressing the problem of an inadequate understanding of workplace learning by exploring alternatives to the apprenticeship model and investigating how skills and knowledge are acquired stands to yield several benefits. Most immediately, research of this nature should ground an understanding of how all individuals, ranging from newcomers to old-timers, learn new things at work. The potential impact on human resource concerns related to education, training and management is considerable. As we have argued, a better understanding of learning should also help explain the social dynamics of knowledge work. For example, to the extent that being knowledgeable equates to possessing power and being rewarded within the firm (Orlikowski 1992), understanding how individuals learn may tell us much about how status and power are gained and how they shape knowledge sharing (Thomas-Hunt, Ogden, and Neale 2003).

More broadly, studies that focus on learning skills and knowledge may inform ideas of how knowledge is distributed, maintained, and shared within an organization, across professional communities, and among firms. Simon (1991:125) noted that “all learning takes place inside individual human heads; an organization learns in only two ways: (a) by the learning of its
members, or (b) by ingesting new members who have knowledge the organization didn’t previously have.” Part of the reason why scholars have difficulty explaining what contributes to a firm’s ability to transfer knowledge and technology is that there are only limited models, theories and empirical data related to how individuals learn in the workplace. Scholars are therefore at a loss to explain and describe one of the two mechanisms, and arguably the primary one, by which firms learn.

In this paper, we undertake a detailed examination of engineering work, work that has the potential to reveal the mechanisms by which individuals acquire skills and knowledge in the social and technical contexts of modern work. Our primary goal is to determine how individuals learn new things on the job, but we also consider what individuals learn. In the course of addressing the questions of how and what, we investigate the degree to which the apprenticeship model – either the traditional model or the transformed version that focuses on identity development – characterizes learning in the workplaces we studied. We explore whether alternative forms of learning exist, and, if so, what role newcomers and old-timers play in these alternative forms. We discuss the importance of the nature of knowledge in determining the form of learning found in each occupation and conclude with implications for theories of workplace learning and socialization.

METHODS

Research Design

We conducted an ethnographic study in California of civil engineers who designed building structures, known in practice as structural engineers, and electrical engineers who designed and tested the hardware components of digital electronic devices, whom we call chip designers. California state law, under Section 6763 of the Professional Engineers Act, restricts the use of
the title “structural engineer” to registered professional engineers. State licensing is mandatory among structural engineers: all building plans must be submitted to local government for approval, and each plan must be stamped by a registered engineer to establish responsibility for the design and liability in the event of structural failure. As part of the licensing procedure, the Act specifies that an engineer must possess at least six years of qualifying experience (Professional Engineers Act, Section 6751) and “must have gained his experience under the direction of a civil engineer legally qualified to practice” (Section 6752). After six years of experience, the engineer must pass a state qualifying examination. The exam tests “knowledge of state laws, rules, and regulations, and of seismicity and structural engineering unique to practice in this state” (Section 6763.1) as well as “the applicant's ability to apply his or her knowledge and experience and to assume responsible charge in the professional practice” of structural engineering (Section 6755). These requirements attest to the recognition of the importance of workplace learning in this occupation. Therefore, if apprenticeships exist anywhere in modern knowledge work, structural engineering seems as likely a home for them as any. Even so, engineers’ initial formal knowledge, gained through years of university education, seems likely to challenge some of the basic premises of the apprenticeship model.

The same law restricts the use of the title “electrical engineer” to registered professional engineers. Most of the chip designers in our sample possessed electrical engineering degrees, but few had undergone the licensing procedure. Unlike structural engineers, chip designers do not submit their designs for government permit. As a result, they are able to carry out their work in the absence of formal licensing. The absence of licensing requirements for experience and training, in conjunction with the rapid pace of advances in knowledge and technology in chip

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5 This exam is the second of two exams in the licensing process. The first exam is taken immediately after graduation from engineering school and tests for “knowledge of appropriate fundamental engineering subjects, including mathematics and the basic sciences” (Professional Engineers Act, Section 6755).
design, provided us with an environment that we suspected might mount a serious challenge to the universal efficacy of the apprenticeship model.

We observed structural engineers at three firms in the San Francisco Bay area. Two firms had 25 to 30 engineers. One of these two firms specialized in seismic upgrades; the other designed many of the single story fabrication plants for the computer chip industry in the Silicon Valley. The third firm employed about twelve engineers spread across three offices; the office that participated in the study employed four engineers. This firm specialized in multi-story steel commercial buildings. We observed chip designers, primarily working on hardware components, at three different firms in the same geographic region. Two firms had fewer than 200 employees, each including 30 to 40 hardware engineers. The third firm had 2000 employees, with 30 to 40 engineers in the hardware group we observed. The two smaller firms designed microprocessor architectures and cores; the third firm made programmable logic devices. Differences in firm specialization and size helped ensure that our findings would not be idiosyncratic to a particular niche or organizational type.

Most of the engineers we observed held Master of Science degrees, a level of education common in both occupations. We observed primarily junior engineers (typically with under 7 years of work experience) and mid-level engineers (typically with 7-15 years of work experience). We also observed a smaller number of senior engineers (having 15 or more years of work experience). We restricted the number of senior engineers we observed because we wanted to focus on engineering work, not management work; as engineers progress through hierarchies, they assume more and greater management tasks. Because senior engineers interact with junior and mid-level engineers frequently during the workday, we had many opportunities to see senior engineers engaged in work. Overall, our selection of mostly junior and mid-level engineers
facilitated a focus on how newcomers learn at work while our observation days with senior engineers provided opportunities to view work and learning from their perspective.

We organized our research team and fieldwork to accommodate the challenges of studying highly technical work. To allow ourselves ample opportunity to delve into the details of tasks, knowledge and technology, we completed almost all observations at one site before moving on to the next. To reduce the possibility that major technological advances might radically alter the nature of knowledge and learning in the field as we progressed from one site to another, we employed multiple observers.\(^6\) That is to say, having multiple observers reduced the time it took us to complete observations at each site, thereby helping us to control for changing technologies by limiting the time span of our fieldwork. The first two authors conducted most of the observations of structural engineers, with two research assistants aiding them. The first and third author conducted most of the observations of chip designers, with three other research assistants aiding them. Over the course of the observations, the first author reviewed the team’s field notes to ensure they were complete, that our methods were consistent across observers, and that events were described thoroughly enough to be accessible to the entire team for analysis.

**Research Process**

We conducted observations of engineers at work, about once a week, between 1999 and 2002. Each researcher followed one engineer per observation, in the process observing other individuals with whom the engineer worked or met. We wrote extensive notes during our observations. Conversations were audiotaped whenever engineers spoke quickly and all taped conversations were transcribed. During each observation, we gathered copies of documents employed by the engineer. Altogether, we supplemented our field notes with more than a

\(^6\) Although less common than individual ethnographic research, examples of collaborative ethnographies do exist (Knorr Cetina 1999, Barley 1996b, see also Geer 1972).
thousand documents, including calculation sheets, drawings, spreadsheets, computer-screen
shots, modeling graphics, and emails. Studying these documents after an observation enhanced
the descriptions we typed into our notes, as when we noted exactly where on drawings engineers
pointed during design sessions. More importantly, the documents we collected served as records
of work and traces of thought processes. The engineers’ calculation sheets, for example, often
revealed which values were assumed, which were determined by field inspection, which were
taken from a design manual, and which were derived in the modeling process. Scrutinizing these
documents helped us more generally to develop an understanding of this engineering work.

We augmented our in-office observations of engineers with several other data collection
techniques and events. On occasion, we conducted hour-long interviews with some engineers to
clarify work practices or to learn more about particular technologies. We interviewed several
managers at the firms to gain insights into policies and to probe their perspectives on knowledge
and learning. We attended numerous office and project meetings, for example a technology
budgeting session and regular progress update meetings. On three occasions, we accompanied
structural engineers to construction sites, where they first met with architects and contractors and
then inspected construction work in progress. Finally, we were tutored on products, tools and
work processes by working engineers not in our sample and by masters-degree students in civil
and electrical engineering.

Our observations lent themselves to the development of a behavioral model of learning rather
than a cognitive one. We mean “behavioral” in the sense of Barker and his associates (1978,
1963), who divided their observations of schoolchildren into units called behavioral episodes.
Examples of behavioral episodes among schoolchildren included “writing a spelling lesson at the
blackboard,” “waiting for the teacher to check spelling,” and “looking at a book” (Schoggen,
Barker and Barker 1963). These researchers categorized episodes according to aspects such as how they were initiated and then compared the frequency of categories across samples. These methods allowed them to report, for example, that a sample of American children produced 1.33 episodes per minute as compared to 0.86 episodes per minute for a sample of English children and that the American children initiated considerably more of their own episodes.

In our observations of engineers, we determined learning instances that were similar in nature to the behavioral episodes demarcated by Barker and his colleagues. A learning instance represented a situation in which knowledge was presented to an engineer or sought out by him. The use of learning instances as a unit of analysis helped us overcome the methodological difficulty of not being able to determine with certainty when or if engineers “learned.” In other words, we could not observe engineers internalizing knowledge, but we could detect when they were in a situation in which learning was a clear possibility. Learning instances provided us a mechanism to focus on learning opportunities rather than outcomes.

In our observations, learning instances were often recognizable because the engineer stopped in his work, unable to progress in the absence of some knowledge. Learning instances also arose when an engineer received unsolicited information. Learning instances were described and demarcated by five factors. Four of the factors concerned how learning occurred: (1) the social nature of the knowledge exchange, (2) the direction in which knowledge was transferred, (3) who initiated the learning instance, and (4) the method by which knowledge was transferred from one individual to another. The fifth factor described what was learned.
The social nature of the learning instance captured whether the learning instance occurred in a dyadic exchange, in a group exchange, or via self-learning.\(^7\) The direction of knowledge transfer varied with the social nature of the exchange. Knowledge in a dyadic exchange might have been transferred, for example, from one junior engineer to another, from a junior engineer to a mid-level or senior engineer, from a mid-level or senior engineer to a junior one, from a senior engineer to another senior engineer, or from some other individual (e.g., a CAD operator or a member of the marketing staff) to a junior engineer. Knowledge in a group exchange might have flowed from a senior, mid-level, or junior engineer to a group, or more rarely, from a group to a senior, mid-level or junior engineer. A junior, mid-level, or senior engineer, or some other person within or outside the firm, might have initiated a learning instance.

Our data yielded five different methods to describe how knowledge was transferred from one individual to another: helping by instructing, helping by working with, providing information, tutoring, and modeling professional behavior. *Helping by instructing* occurred when one person helped another by providing instruction, typically in the form of steps to be taken in a design or analysis task or solving a larger problem. When helping by instructing, engineers rarely left their own desk or interrupted their own work for more than a few minutes. Instead, they tended to rattle off lists of steps, encouraging the learner to return if more questions arose. *Helping by working with* occurred when one person helped another by working with her on a problem. For this mode to apply, the helper had to become absorbed in the problem, for example by looking at specific values or drawings or by taking on the problem almost as his own. Often the engineer providing the help would leave his own desk to accompany the learner to her workspace where together they examined the problem in detail. *Providing information* signified the

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\(^7\) Three of the remaining four factors were not deemed to apply to self-learning instances, which had no direction of knowledge flow beyond perhaps from a material resource to the individual (but not always that), no initiation beyond the self, and no method beyond self-learning. Self-learning instances did have subjects of learning.
straightforward provision of information from one person to another. Information included objective data, facts, values, specific project information, and low-level procedural details, such as how to select an object in a CAD program. Information tended to be short (as opposed to instructions, which could be long), thus its transmission was typically quite rapid. Tutoring occurred when the person providing the learning opportunity adopted a pedagogical attitude and tried to convey general concepts. Tutoring was often recognizable because the engineer providing the help would eventually digress from the particulars of the problem to extract larger, more general lessons from the situation. Individuals who adopted a tutoring mode often quizzed the engineer on fundamentals associated with the problem rather than offering straightforward help. Modeling professional behavior occurred when one engineer was present when a colleague was engaged in a professional activity (e.g., negotiating with a contractor or a customer) during which the engineer may have learned how to act in that role. Modeling of this sort was indicated when no particular problem had been presented to the engineer providing the help; instead, his own behavior in a situation offered an opportunity for learning.

The knowledge subjects that reflected what was learned fell into five types: technical content, tools, procedures, political factors, and organizational factors. Technical content included materials, elements, theoretical concepts, empirical data, rules of thumb and other items that were engineering, mathematical, or scientific in nature. Tools captured all learning related to workplace technologies, including simulators, analysis packages, drawing implements, and email. Procedures referred to company or professional routines or processes, such as how to load code files in the common file repository and how to submit drawing and calculation packages for county permit. Political factors included knowledge related to the roles and responsibilities of various parties both internal and external to the firm, how they constructed or
viewed the world, and how to communicate and negotiate with them. *Organizational factors* included topics related to project management, human resources, budgeting, and scheduling.

We coded the learning instances for the aspects described above via an iterative, comparative process. Beginning with subsets of the structural engineering notes, two or more researchers coded the same material and then discussed differences in their results. We repeated this step for subsets of the chip design notes to make sure that our codes applied equally well in this occupation. After making necessary adjustments, we proceeded to code and analyze all of our field notes. Upon completion of our analysis, we shared our results with a number of the engineers we had observed in both disciplines. Their acceptance of our findings provided an additional measure of confidence in the soundness of our methods.

**HOW ENGINEERS LEARN AT WORK**

Workplace learning was prevalent in both engineering occupations that we studied. We observed learning instances among structural engineers at an average rate of 1.2 instances per hour and among chip designers at 0.8 instances per hour, revealing a considerable amount of workplace learning in both fields. How this learning occurred differed considerably between the two occupations but was remarkably similar within each one (i.e., across the three firms in each occupation). The discovery of two models disproves the universality of a single model of workplace learning and suggests the validity of occupational models. We describe the version of the apprenticeship model we found to apply in the structural engineering workplaces and the “guru” model we found to apply in chip design.

**Structural Engineers As Modern Apprentices**

Learning in the structural engineering workplace was well characterized as an apprenticeship, but one that differed in several striking ways from transformed versions of apprenticeship that
focus on role socialization. Corresponding to the four factors that described how learning occurred (social nature of learning instances, direction of knowledge flow, method, and initiation), important features of the apprenticeship model seen in the structural engineering workplace included (1) a predominance of dyadic learning, (2) asymmetric flow of skills and knowledge (3) a culture of inequality, and (4) predetermined learning for juniors.

**Predominance of Dyadic Learning.** True to conventional notions of apprenticeship, dyadic exchanges dominated the learning instances among structural engineers. As shown in Table 1, which summarizes our findings, dyadic exchanges were the most frequent type of exchange, characterizing 72% of all learning instances among structural engineers. These dyadic exchanges typically took place in cubicles or around tables as the engineers pored over drawings or computer analysis results. Learning within groups constituted the bulk of the remaining learning instances (23%) in structural engineering. Such instances typically occurred in one of two settings: staff meetings in which news was reported (e.g., information gained at a recent conference or through a peer review) or project design sessions that typically involved a small group of perhaps three or four engineers. Self-learning constituted only 5% of the learning instances that we observed among these engineers.

**Asymmetric Knowledge Flow.** To a striking degree, skills and knowledge flowed asymmetrically from senior engineers to less experienced ones. Juniors were the learners in 69% of all learning instances; mid-level engineers were the learners in just 16% of instances and seniors were in only 2%. Seniors taught in 62% of instances, mid-level engineers in 9%, and juniors in 23%. (Invariably, when juniors taught they taught other juniors.) The pattern of juniors as learners and seniors as their teachers is strongest in dyadic exchanges. In 96% of the

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8 Because we shadowed only a small number of senior engineers, we undoubtedly missed many instances in which they learned. Our data make clear, however, that senior engineers were almost always the teachers when engaged with junior or mid-level engineers.
junior-senior dyadic exchanges, the senior engineer imparted skills and knowledge to the junior engineer. This pattern of knowledge passing from a more experienced engineer to a less experienced one persists throughout the hierarchy: The mid-level engineer imparted knowledge to the junior one in 83% of exchanges involving two such engineers; the senior engineer taught the mid-level one in 100% of all exchanges involving senior and mid-level engineers. Overall, in all dyadic exchanges involving a junior engineer, a senior or mid-level engineer taught a junior one 62% of the time. Juniors taught each other in 27% of all dyadic exchanges involving a junior. Junior engineers taught more experienced engineers in only 4% of these instances and taught others (e.g., CAD operators) in only 2% of them.

As in dyadic exchanges, senior engineers were most often the teachers in group-learning instances; this occurred in 77% of all such instances. Juniors taught the group in only 7% of such instances and mid-level engineers in none. Mixed groups or other individuals both inside and outside the firm (e.g., CAD operators, contractors) taught in the remaining group-learning instances. These patterns of learning across dyadic exchanges and group-learning instances provided strong evidence that skills and knowledge were greatest among senior structural engineers.

Culture of Inequality. The asymmetric exchange in learning instances that resulted from this knowledge imbalance characterized an occupational culture of inequality in the structural engineering workplace. In this culture, new hires were explicitly understood (by colleagues and themselves) to be incompletely educated; it was presumed that they would accrue mastery slowly with strong guidance and teaching from senior engineers. Junior and mid-level structural engineers appeared to respect the skills and knowledge of their seniors; for example, in our observations they rarely challenged senior engineers’ opinions or techniques.
Senior structural engineers transferred skills and knowledge to juniors through a variety of learning methods. Helping by working with was the predominant method; it was employed in 39% of all learning instances involving two or more people. This method of transferring knowledge afforded routine and close access to masters of the practice, thus facilitating the transparency of expert work for junior engineers. The provision of information was also a common mode, accounting for 24% of all non-solo learning instances. Tutoring and helping by instructing represented 17% and 18% of all such instances, respectively. The only method not commonly employed was modeling professional behavior, which accounted for only 2% of all learning instances involving two or more people.

Predetermined Learning. In this world of masters and apprentices, where the early road to becoming a full-fledged structural engineer was specified by state law, senior engineers largely controlled the timing, pace and content of what we termed “predetermined learning” for the junior engineers. Notably, senior engineers initiated fully half of the learning instances in which junior engineers were the learners. Predetermined learning was evident, for example, in the case of Sheila, who had been waiting more than a year to learn a software package for analyzing concrete structures that she estimated would take only four hours to learn. Sheila believed that learning how to use this package would increase her skills and broaden the set of projects to which she could be assigned. But because engineers’ hours were billed to client projects, Sheila was required to wait until her supervising engineer approved the time it would take to learn the new package, time that could not be billed to any single project. In this manner, the senior

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9 Notably, master-apprentice pairings usually changed each time a project ended. As a result, master-apprentice relationships were exclusive only for short periods of time, typically a few months. The fluidity of pairings reflected one way that the apprenticeship model of structural engineering differed from conventional notions of apprenticeship.
engineer’s plans for Sheila’s learning took precedence over her own desires. Assigning junior engineers to certain types of projects (for example, wood, steel, or concrete structures) was another route by which seniors controlled what juniors learned and when they learned it.

**Chip Designers As Gurus Among Equals**

In striking contrast to the apprenticeship model of structural engineering, a “guru” model best characterized learning in the chip design workplace. In this model, engineers learned from experts or “gurus” who possessed specialized knowledge. These gurus were primarily engineers in the firm. At least four different kinds of gurus populated the chip design workplace: gurus for specific components, including microprocessor cores and their peripherals (e.g., a multi-gigabit transceiver, a memory module); gurus for specific tools (e.g., a simulator or the configuration management software); gurus for specific languages (e.g., general purpose languages like Perl as well as languages specific to electronic design like Verilog); and gurus for overall technical knowledge (e.g., domain specific knowledge like that for digital signal processing as well as more general technical knowledge like probability theory).

Several features distinguished the guru model in chip design, corresponding to the four factors that we used to describe how learning occurred: (1) a predominance of dyadic learning, (2) flow of skills and knowledge among engineers in directions independent of seniority, (3) a culture of equality (4) autonomous learning management for each engineer. Notably, the guru model found in chip design differed from the apprenticeship model of structural engineering in every aspect except the prevalence of dyadic learning.

*Predominance of Dyadic Learning.* As in structural engineering, dyadic exchanges dominated learning in chip design, accounting for 75% of all learning instances. Group learning

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Sheila could not learn the package at home because she had no home computer and there was no network connection from her home to the firm. Learning it after hours or on Saturday at work was not an option because the firm disallowed overtime pay and discouraged extra, unpaid work.
instances occurred rarely in this occupation, however, constituting only 8% of learning instances. Instead, self-learning instances were much more common, representing 17% of all instances (as compared to only 5% in structural engineering).

Symmetric Knowledge Flow. Remarkably, in the guru model of chip design, junior, mid-level and senior engineers all taught. In fact, junior engineers were nearly as likely to act as teachers as they were as learners. For example, in junior-senior dyadic exchanges, the junior engineer taught the senior one 40% of the time. (Among structural engineers, this value was only 4%.) In exchanges with a mid-level engineer, the junior engineer taught 45% of the time. Overall, in all dyadic learning instances involving a junior engineer, the junior engineer taught a more experienced engineer in 24%, taught another junior engineer in 30%, and taught some other party (e.g., architect or CAD operator) in 5%. The junior engineer was taught by a senior one in only 9% of dyadic exchanges involving juniors, by a mid-level engineer in 22% of them, and by some other party in 10% of them. Senior engineers were predominantly the teachers in group-learning instances (56% of all such instances), but as we noted, group learning was uncommon.

Culture of Equality. These patterns of learning revealed that junior chip designers were not novices to be guided and tutored by their seniors. Rather, junior engineers in this field possessed considerable skills and knowledge, often of the sort that their more experienced colleagues lacked and needed. Thus, experience was not correlated with knowledge among chip designers; all engineers possessed considerable knowledge. Senior engineers often turned to junior engineers for help and consequently a culture of equality permeated these workplaces.

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The difference between 17% and 5% does not mean that self-learning occurred more than three times as often in chip design than in structural engineering. Because the total number of observed learning instances was not identical across the two occupations, the percentages are best employed to compare the prevalence of a given event versus other events only within occupations and to note relative, not absolute, differences across them.
The culture of equality that existed despite differences in experience was revealed in the attitudes and behaviors of junior chip designers, who freely challenged the statements of mid-level and senior engineers. The concept of “old-timer” – an experienced engineer who should command respect – did exist among chip designers, but was usually said in friendly jest. For example, at one firm a junior engineer teased another engineer that “only old-timers” knew how to build and test files in a particular computer directory. That “old-timers” referred in this instance to individuals who had been with the firm as little as one and half years, when the directory was created, is testament to the dynamic nature of knowledge in chip design, a point we return to later.

This culture of equality was further reflected in the methods engineers employed to teach one another. The dominant mode for conveying skills and knowledge in chip design was the simple provision of information, accounting for 74% of all learning instances involving two or more people. This value was much higher than the corresponding value, 24%, among structural engineers and presumably reflected the chip designer’s primary need not for guidance but rather simply for information. Learning via helping by working with, the primary mode of learning among structural engineers, constituted a distant second-place method among chip designers, accounting for only 15% of all learning instances involving two or more people. Helping by instructing accounted for another 10% of all such learning instances. Tutoring represented only 1% of learning instances involving two or more people; in the rare instances when someone did adopt a tutoring tone, it appeared to be resented. There were no instances of modeling professional behavior among chip designers.

*Autonomous Learning Management.* Absent a master and a clearly charted path to “becoming” an engineer, chip designers exhibited a learning strategy that we termed
“autonomous learning management.” Via autonomous learning management, chip designers actively controlled and determined what they would learn. For example, Rajeev, a junior in one firm, told us that he generally was willing to investigate a bug he suspected to exist in someone else’s code (which his own code called) only if that code was associated with a well-established component. Debugging the code would require Rajeev to learn about the mechanisms associated with that component, for example, its functions and the manner in which it responded to instructions. If the component was well established, there was a reasonable chance that the code would be well documented, which would make learning easier for Rajeev. If it was not, Rajeev was unwilling to invest the energy to pursue what he imagined would be a messy problem. In another example of autonomous learning management, Eric, a senior chip designer, tried to persuade Jason, a junior one, to work on his project. Jason asked Eric what kinds of tasks he might be able to work on. Jason then assessed the attractiveness of the tasks based on what he might learn in doing them.

Evidence that junior chip designers had control over their own learning was the fact that they initiated more than 90% of the learning instances in which they were the learners. (By contrast, junior structural engineers initiated only 48% of their learning instances.) That chip designers engaged in considerable self-learning (17% of all instances we observed) may constitute further proof of their autonomous learning management because self-learning often occurred when an engineer deemed something worth knowing and then took the time to teach himself without asking anyone’s permission. In fact, the ability to learn on one’s own was something chip designers sought in potential new hires. Chip designers were expected to “do their homework” before interrupting a guru with a question. Some gurus enforced this norm by firing toy water guns at colleagues who asked questions that were addressed on web frequently-asked-question
Web pages. Through such expectations, chip designers promoted the autonomy of learning and a culture of capable equals.

**WHAT ENGINEERS LEARN (AND DO NOT LEARN) AT WORK**

Although we found different models of how learning occurred across the two occupations, what both kinds of engineers learned was similar in many respects. Both structural engineers and chip designers primarily learned technical content, the case in more than 50% of the observed instances in each field. In the chip design workplace, examples of learning technical content included learning how a particular instruction operated in assembler code, being told how to implement special functions in diagnostic tests, and discovering how data registers were implemented. In the structural engineering world, examples of learning technical content included being tutored on how to space steel reinforcement bars, finding out how to calculate tributary areas for oddly shaped floors, and being instructed on how moment (force multiplied by distance) traveled through a particular building section.

In chip design, almost all of the rest of learning was about tools, for a total of 36% of all learning instances. Examples of tool learning in chip design included being told how to integrate files into the software configuration management tool, sorting out the intricacies of the commonly employed “make” command, and being told why an error message on a logic checking tool could be ignored. The large number of instances of tool learning reflected the ubiquity of the computer as a tool for chip design work. By comparison, only 10% of the learning instances among structural engineers concerned the tools they employed. We often observed structural engineers working for hours without a computer, often employing little more than a calculator, pencil and design manuals or building codebooks.
Rather than learning about tools, structural engineers frequently learned about procedures, which constituted 21% of all their learning instances. Examples of learning about procedures included learning when a more detailed drawing was appropriate, being told how to reference external reports on calculation sheets, and being informed about what types of documents to present to architects and building owners. The corresponding value for chip designers was a mere 4%.

Learning related to politics was also more evident in structural engineering (13% of all learning instances) than in chip design (only 2%). An example of political learning arose when a senior structural engineer told a junior one how comments that she wrote on drawings could cause liability problems and thus should be restated. Learning about organizational factors included learning how to calculate personnel workload and allot engineers’ time over the course of a project. This type of learning was rare (under 2%) in both domains.

Notably, we did not observe much role-related learning, in the sense of learning “how to be” either a guru among chip designers or a master among structural engineers. Interestingly, the reasons for the absence of learning about how to fulfill one’s role within the community of practice seemed to differ by occupation for the engineers in our study. We did not observe chip designers engaged in instances of learning how to be a guru. Instead, they showed evidence of having already learned how to be a guru in that, regardless of years of experience, all chip designers behaved like gurus. For example, we did not see chip designers discussing how to manage interruptions of their time, yet they all permitted frequent interruptions from multiple individuals (and occasioned them as well). We never saw a chip designer receiving or giving advice about how to set up a web page to handle common inquiries, yet many engineers posted such pages. That junior chip designers seemed to know how to act as gurus suggests that guru
behavior may have been learned prior to entering the workplace. Chip designers may have learned how “to be” gurus through earlier experience in the workplace, for example via summer internships. It is also possible that graduate school electrical engineering labs so closely mirror the culture and norms of the chip design workplace that learning how to be a guru could be accomplished there.  

In contrast with chip designers, who appeared to enter the firm knowing how to act as gurus, junior structural engineers seemed to spend little time seeking to acquire the traits and behaviors exhibited by masters. Instead, junior structural engineers appeared overwhelmingly preoccupied in the short term with accomplishing their work tasks and in the long term with gaining the knowledge required to pass the second exam for certification. On several occasions, junior engineers expressed their concerns to us about not yet learning certain technical material, often because they had not been assigned to certain kinds of projects. Universally low pass rates for the second exam may have motivated junior engineers to concentrate their efforts on learning technical content rather than role-related behaviors while on the job. Conceivably, junior structural engineers could have learned how to be master teachers simply by observing how senior engineers behaved when interacting with them in their near-daily reviews. The junior structural engineers, however, appeared to be more concerned during these review sessions with defending their decisions than with learning pedagogical techniques. The mid-level structural

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12 Conversely, because junior chip designers were regarded largely as equals, it may be that they had more influence in shaping the culture of the workplace than did their structural engineering counterparts, and as a result transformed the workplace to resemble graduate labs. This explanation may help to account for differences like the prevalence of toys and games in chip design workplaces and their absence in structural engineering ones. It is unlikely that this difference was due to differing labor market conditions, as the market for both types of engineers was tight during the period of our study. Rarely did customers or other outsiders enter either type of workplace, which rules out explanations based on the need to maintain professional decorum in the workplace.

13 During the period from 1999-2002, the average pass rate in California was just over 27% for the second exam (California Board for Professional Engineers and Land Surveyors 2003). Nationally, the pass rate was 67% for first-time takers and 34% for repeat takers for the 2003 National Council of Examiners for Engineering and Surveying (NCEES) PE Structural I exam, which is administered by a number of states and is similar to the second California exam (NCEES 2003). First-time statistics are not available for the California exams.
engineers’ preoccupation during our observations with many of the same kinds of design and analysis tasks that junior structural engineers engaged in, and the prevalence of senior rather than mid-level engineers teaching junior ones, may indicate the elongation of the role-transformation process in this occupation.

To summarize, we saw engineers in both fields engaged in fairly little of the kind of role socialization process that we would consider personal transformation or “becoming” gurus or masters. This is not to say that we challenge the notion that individuals must and eventually do learn the social behavior associated with associated with their occupational roles. We do contend, however, that defining all learning as the personal transformation of one’s sociocultural role diminishes the importance of (and distracts attention from) the acquisition of skills and knowledge. Such acquisition dominated the learning among engineers in both the occupations we observed. The preponderance of observed instances of learning about technical skills and knowledge suggests that to define learning solely as a role socialization process is to miss a major portion of the picture of the on-the-job learning of engineers.

Further problematizing a view of learning as synonymous with the social behavior of an old-timer is the disparity in that process between the two occupations. Clearly, while master and old-timer behavior are isomorphic between conventional apprenticeships and structural engineering firms, behaving like a guru in the chip design firms does not neatly map onto behaving like an old-timer. The inability to correlate experience with role may derive in large part from differences in the rate of change of knowledge in these two occupations, a conclusion that would shed light on when the apprenticeship model is likely to apply.
THE IMPORTANCE OF KNOWLEDGE IN MODELS OF LEARNING

We noted in the beginning of this paper that the apprenticeship model might be expected to fail to cover at least three situations: (1) when the rate of knowledge change is rapid, (2) when knowledge is specialized, and (3) when newcomers already possess work-related knowledge. The two occupations that we observed differed considerably in the rate of change of the fundamental knowledge of the field. In structural engineering, knowledge is relatively static, especially compared to chip design, where knowledge is notoriously dynamic. Additionally, knowledge in chip design is specialized, whereas knowledge in structural engineering is far less so. We found that an apprenticeship model applied in a field where the rate of knowledge change was slow and knowledge was not specialized; in a field where the rate of knowledge change was rapid and knowledge was specialized, we found a guru model instead. In both occupations, however, newcomers to the workplace possessed considerable knowledge upon entry. This factor did not seem to preclude the existence of an apprenticeship model among structural engineers. We describe how these three factors – rate of knowledge change, specialization, and newcomer knowledge – were manifested in our observations and consider their relationship to the forms of workplace learning that were displayed.

Importance of the Rate of Change of Knowledge

Fundamental structural engineering knowledge advances slowly. This knowledge includes knowledge of established properties of materials, mathematical equations and models, industry standards, and the normal configurations and uses of building components. The slow rate of change in this knowledge should not be surprising. Buildings have been constructed for thousands of years and most types of materials employed today have existed for many decades. The slow rate of change is evidenced in the infrequent re-issue of design manuals,
manufacturers’ brochures, and building codes that contain such information as the physical limits of various elements (e.g., beams, columns, and bolts) as well as accepted (and often mandated) design practices. These documents are only updated every two to three years, with much of the content unchanged. Much of a structural engineer’s basic knowledge therefore remains current throughout her career.

Though enduring and stable, fundamental structural engineering knowledge was certainly not irrelevant to modern, everyday practice. Quite to the contrary, we witnessed structural engineers employing fundamental knowledge in their daily work of design and analysis. Discussions of tension and compression, concepts that engineers first encounter in sophomore-level statics courses, frequently took place over drawings and analysis results. Fundamental knowledge also served as the basis for any new knowledge the engineers generated in the course of practice (e.g., knowledge implicit in a new design). For example, we observed an engineer develop a connection to secure a column to a floor; although the design was novel, the connection consisted of standard elements simply brought together in a unique way. The relevance of acquired knowledge was further apparent in design conversations as senior engineers routinely recalled designs from past projects, sometimes a decade or more old, for re-use in a current project. The enduring applicability of fundamental knowledge meant that a senior engineer’s status as master was unlikely to be diminished or revoked with time.

Certainly, significant advances have occurred in the workplace technologies that structural engineers employ in design and analysis, but these technological changes have not precipitated a surge in the rate of change in knowledge required to perform work. The advent of desktop computers facilitated the use of sophisticated analysis programs (e.g., finite element analysis software) that could not have been employed feasibly with past technologies. The junior
engineers we observed arguably had better facility with such programs than their seniors, but approximate methods in the form of rules of thumb and simplifying equations that senior engineers employed as they came through the ranks remained valid. These approximate methods enabled senior engineers to quickly verify results from sophisticated analysis software programs.

Moreover, the structural engineering firms we studied rarely acquired new workplace technologies. Commercial design and analysis packages purchased more than a decade ago remained in frequent use and high-powered computers, although desired, were not necessary. The low turnover of tools meant that tool knowledge remained relevant for a long while. (Recall that only 10% of the learning instances among structural engineers concerned tools.) Consequently, senior engineers’ knowledge did not require significant updating and their role and status as masters were not greatly threatened by advances in workplace technology. Overall, the slow rate of change of knowledge in structural engineering facilitated an apprenticeship model.

Compared to structural engineering, chip design relies on knowledge that is far more dynamic, local and short-lived. The technological advances that render component geometries ever smaller in chip design also engender new workplace technologies to help engineers cope with increasing product complexity. The frequent (often annual) replacement of old technologies with new ones was one factor that made the master role less relevant among chip designers and presumably explained the evolution of the tool guru.

Although technological advances were frequent and strongly influenced how and what chip designers learned, they represented only part of the rapid knowledge change in this field. Similarly frequent changes occurred in knowledge about components, languages, and technical topics and helped account for the emergence of the three other types of gurus. In fact, frequent
changes in knowledge often meant that a guru’s knowledge became obsolete. Specifically, when a firm purchased a new tool for a particular task, such as the checking of logic within code, an engineer other than the current tool guru for this task might have been sent for vendor training and thus become the new guru for this tool. Similarly, new project assignments occasioned by a newer version of the microprocessor or related components often meant that a different engineer became the guru for a particular component in its next release. An engineer who was sent off to a class to learn a programming language could have become the new guru in that language if the changes in the latest version of the language were significant. Finally, advances in design techniques and manufacturing technology may have prompted changes in who constituted a guru in a technical knowledge area, perhaps because of more recent academic education. Guru status therefore was temporally dynamic across all types of gurus.

The rapid pace of knowledge change in chip design worked against the possibility of an apprenticeship model in this occupation. Assigning a specific individual to become the firm’s repository for knowledge about a particular topic ultimately reduced the cognitive load for the other engineers. In this manner, the guru model helped chip designers contend with the dynamics of knowledge in their work.

**Importance of the Specialization of Knowledge**

Our observations and interviews suggested that the work of structural engineering and chip design is characterized by an inordinate amount of knowledge that is applied in everyday tasks. For structural engineers, the base of fundamental knowledge is so vast that years of formal education are insufficient for gaining all of it. Upon joining the workforce, structural engineers

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14 Different products and product versions were staged in their development. The group might have been developing simultaneously the last product families of the previous version of the microprocessor, the first families of the current version, and the early ideas of the next version. A guru on the most recent past version of a component may not have been the guru on its current version but could have become the guru on the next one.
spend several more years learning a considerable amount of established and practical knowledge on the job. After their university education, chip designers also learn a considerable amount on the job, where they are inundated with the sheer volume of knowledge required by their work. In language that revealed just how much knowledge is needed, one junior engineer remarked that his “brain was full” and thus he was very selective in terms of what he agreed to learn at work. Although both fields depend on tremendous knowledge domains, knowledge is specialized only in chip design.

In structural engineering, there is little specialization of skills and knowledge among senior structural engineers, who as generalists are able to fully and capably create designs for and manage all types of projects regardless of the material (e.g., concrete, steel, or wood), the primary criteria the firms used for differentiating building structures. The culture of inequality thus reflects differences in skill and knowledge vertically along the organizational hierarchy, not horizontally. We rarely observed structural engineers seeking out a particular senior engineer for help because of her specialized knowledge about engineering theory, practice, or tools. Instead, a junior engineer typically addressed his questions to the senior or mid-level engineer assigned to his current project. Ultimately, all structural engineers were expected to acquire the same broad range of knowledge. Senior engineers, who presumably possessed mastery over this range, were therefore fairly interchangeable as teachers. As evidence, if the senior engineer on his project were not available when a junior engineer sought him out, the junior engineer often would turn to any senior engineer who appeared available to lend help.

With time, a structural engineer gains broad knowledge across the entire spectrum of structural engineering know-how. Experience is slowly accrued project by project as engineers are exposed to a wide array of structural elements, garner greater knowledge of materials and
design options, and learn new ways to apply the profession’s fundamental knowledge. Managers recruit new engineers not on the basis of any specialized expertise, but rather for more general qualifications, namely a strong grasp of fundamental engineering theory, undergraduate design experience, and analysis experience at the master’s-degree level. The breadth of knowledge a master engineer accrues with experience is sufficient for her to design an entire building structure herself. Pressures to complete projects quickly and the desire, in fact responsibility, to train junior engineers largely account for staffing more than one engineer on a project.

In chip design, by contrast, knowledge is distributed across a specialized network, with each engineer holding a piece of the larger puzzle. Evidence of the specialized network was reflected in chip designers’ choices when seeking help. These engineers invariably turned to a specific individual each time they sought assistance. An engineer might stop working on computer code to announce that he had to “go ask Rob a question.” If the targeted individual was not available, the engineer might turn to a past guru for information. Different requests were made of different individuals in line with their varying expertise. In contrast with structural engineers, the chip designer’s first instinct was not to consult the senior engineer leading her project or even an engineer assigned to the same project, but rather to seek the person who specialized in her type of problem. Overall, unlike masters in the world of structural engineers, chip-design gurus apparently were not interchangeable.

Chip designers’ acquisition of skills and knowledge is a significantly different process from the upward progression of junior structural engineers. Chip designers do not move “upwards” because their goal – aligned with the expectation of their peers and seniors – is not to acquire all the knowledge of the discipline (an accepted impossibility), but rather to acquire specialized knowledge. Thus, they traverse the distributed knowledge network in their firm in a jagged,
lateral manner, each engineer taking a unique path. In the process, chip designers gradually gain deep knowledge in an increasing number of areas. Senior engineers differ from junior ones not so much in the depth of their knowledge in any particular area, but rather in the number of areas in which they have deep, albeit at times outdated, knowledge. Recognizing that they cannot hope to learn the entire domain, these engineers appear to seek expertise in a combination of sub-areas that satisfies their needs. These needs include becoming more marketable, staying current in a technology, and gaining status by getting engaged in cutting-edge projects.

One could argue that the high rate of knowledge change was the primary factor that hindered an apprenticeship model in chip design and that the specialization of knowledge in this field was simply an artifact or outcome of the guru model. Alternatively, the specialization of knowledge may help explain the inappropriateness of an apprenticeship model. Specialization of knowledge in chip design may be driven as much by the organization of work (for example, in response to competitive markets and short product lifetimes) as it is by the rate of knowledge change. (In comparison, structural engineers bid for their projects and there is no “rush to market.”) Our data cannot resolve the question of the role of specialization of knowledge in determining the learning model. They do make clear, however, that such specialization appeared only in chip design, where a guru model of learning was employed.

**The Importance of Distinguishing Novices from Newcomers**

No one would deny that someone newly hired or contracted into a firm is an organizational newcomer. But one cannot assert with equal confidence that an organizational newcomer is an occupational novice. Obviously false in the case of individuals who switch firms late in their careers, the association of novice with newcomer may also be unwarranted for entrants into their first employment position, as it is in the case of chip designers. Yet, researchers who construe
workplace learning strictly in terms of role socialization and identity transformation make
exactly this mistake. Lave and Wenger (1991), for example, defined newcomer and old-timer in
terms of social position and not possessed skills and knowledge per se. In their theory, the
relative status of newcomer and old-timer would not change even if the newcomer were more
expert than the old-timer in a particular subject or skill. Thus, Lave and Wenger would assign
even a knowledgeable newcomer to the learner role, presumably because of the long journey that
lies in store for the newcomer to “become” a full participant in the community of practice.

The chip design (guru) model of learning highlights the problems that derive from this
conceptualization of the newcomer’s knowledge. In chip design, new junior engineers possess
current, relevant knowledge and senior engineers learn nearly as often from junior engineers as
the reverse. Newcomers thus cannot be equated to novices in this occupation. Similarly, old-
timer is not synonymous with expert: Old-timers are experts in some areas, but so are
newcomers and everyone in between. Construing all workplace learning as role socialization
and identity transformation ignores the possibility of more universal learning within the
workplace and consigns the newcomer to the lowermost, or outermost, position in the knowledge
community.

One question that remains is why an apprenticeship model holds in structural engineering
despite the considerable knowledge held by new engineers freshly graduated from university
programs. Our initial specification may have been too simplistic: What matters is not whether
newcomers possess knowledge or not, but rather the status of that knowledge relative to the
knowledge of other members of the community of practice. Junior chip designers hold unique
knowledge that is more current in some areas than the knowledge possessed by other engineers
in their firms. Junior structural engineers hold knowledge that is largely redundant with the
knowledge held by structural engineers already in their workplaces. Moreover, the store of
knowledge held by seniors is vastly superior to what junior structural engineers hold. The
apprenticeship model, with its depiction of the newcomer as novice, is thus apt.

It seems reasonable to expect that other occupations might mirror the situation of chip
design. One can conceive, for example, of occupations whose fundamental knowledge changes
so rapidly that new college graduates hold a great advantage over senior individuals; computer
science may be one such field. One can also envision occupations in which knowledge is largely
idiosyncratic to contextual situations that change frequently or dramatically, thus limiting the
value of experience. In such instances, individuals already in the workplace would be as
disadvantaged as fresh graduates and all would need to learn. Possibly, automobile or computer
repair reflects these conditions. These cases illustrate that experience – and the knowledge
gained from it - may not prove as influential in determining an individual’s role and status as it is
portrayed by theories of workplace learning that focus on role socialization. The knowledge of
newcomers thus must be carefully considered in light of the knowledge of practicing members of
the occupation and the relationship of knowledge to work.

IMPLICATIONS

Our study reveals the prevalence and importance of workplace learning in two modern
technical occupations. As the dictates of state licensing suggest, workplace learning was critical
for newcomers in structural engineering. But even in chip design, where the absence of formal
apprenticeships and licensing requirements with respect to experience suggest a limited value for
on-the-job learning, we found that workplace learning was ubiquitous and crucial. Although
both occupations exhibited considerable workplace learning, they featured very different models
of learning. The chip design model is significant for researchers because it demonstrates the
existence of a form of workplace learning other than apprenticeship. The structural engineering model confirms the existence of apprenticeship in modern knowledge work, but in a form that closely parallels conventional notions of apprenticeship that focus on skill acquisition. Both models highlight the serious limitations of theories that frame learning, and in particular workplace learning, primarily in terms of role socialization and the transformation of an individual’s identity within a community of practice.

Our discovery of two different models of workplace learning, one for structural engineers and the other for chip designers, demonstrates the validity of occupational models of workplace learning. Although we studied six firms, we did not discover six forms of learning, nor did we discover a single, universal model. Rather, one model for each occupation emerged as the most appropriate characterization of the learning processes we observed. This finding suggests that firm-level factors may not be instrumental in shaping the model of learning that emerges. In fact, because a firm’s workforce often reflects many occupations, multiple forms of learning may exist within a single organization. Overall, we predict that a variety of learning models can be found, extending beyond the apprenticeship and guru models that we documented in these two engineering occupations.

Consideration of a range of learning models should prove useful in helping scholars think about modern work. To begin, specification of multiple models of workplace learning would help distinguish modern occupations in ways that are meaningful for knowledge work. Barley and his colleagues (Barley and Kunda 2001, Barley 1996b) argued that current descriptors of work, including cultural dichotomies, occupational archetypes, and formal classifications, are based upon outdated images of work rooted in an industrial age. These descriptors often do little more than separate manual work from mental work or blue-collar from white-collar jobs,
distinctions that are unhelpful in differentiating among technical and professional occupations. Examining how workers learn on the job would advance the study of modern work by uncovering occupational knowledge differences that could help serve as the basis for classifying knowledge work.

Our findings further demonstrate how paying attention to learning about skills and knowledge is important for understanding the social dynamics of the workplace. Our study reveals, for example, why status is associated with experience among structural engineers but not among chip designers. A focus on learning provided the means for us to discover and understand why chip designers prefer to hire self-starters and why structural engineering firms look for newcomers with a strong grasp of engineering fundamentals. Although we did not investigate issues of turnover and mobility among engineers, our findings with respect to learning would likely contribute to an understanding of these phenomena as well. Our findings suggest, for example, that structural engineers would be unlikely to switch firms before passing the second licensing exam, whereas chip designers would feel freer to move whenever they deem their opportunities for learning to be too narrow.

The benefits of paying attention to the acquisition of skills and knowledge in workplace studies include a deepened understanding of organizational culture. Differences in how engineers learn skills and knowledge – including from whom they learn, the methods by which they learn, and who initiates the learning – help explain differences in culture that we observed across these occupations. Our findings elucidate the culture of inequality that characterizes the structural engineering workplace and make clear why junior structural engineers defer to their seniors. Senior structural engineers display mastery of technical skills and knowledge, they control what and when a junior engineer learns, and they are mandated by the state to guide his
practical education in preparation for the licensing exam. Junior structural engineers do not rebel at being tutored or at having senior engineers stand beside them and help them by working with them through design and analysis problems. They may attempt to defend their own decisions, much as Bosk (1979) noted young doctors doing when they were questioned during rounds by attending senior physicians, but they do not challenge the senior engineers’ opinions. Similarly, our study makes clear why senior chip designers do not command similar respect from junior engineers merely on the basis of their longer job tenure. Junior chip designers act as and are treated as equals to their seniors. They learn primarily by simply providing each other with information; they almost never tutor. And they delight in teasing old-timers about outdated knowledge.

Scholars of organizational culture rarely consider processes of skill and knowledge acquisition when constructing models of how firms develop cultures. Although role socialization within occupations is about nothing else if not the transfer of a group’s culture to an individual, the kind of cultural differences we observed arose not in the context of role socialization but rather in the context of the acquisition of skills and knowledge. This result suggests that the creation and transmission of organizational culture may be strongly influenced by the processes of technical learning on the job and underscores how developing an understanding of these processes might fundamentally inform organization theory.

Our findings further highlight the value gained from paying attention to learning about skills and knowledge when exploring how knowledge is acquired, maintained and transferred in firms. Brown and Duguid (1991), who argued that much of conventional learning theory separates learning from working to its detriment, lobbied for the importance of paying attention to the details of work when investigating organizational learning and innovation. Our attention to these
details helped us to map the organization of knowledge within each engineering occupation. Although both learning models exemplify “transactive memory systems” (Wegner 1987) within the firms, knowledge in structural engineering firms is vertically organized, with top-down transfer from senior engineers to junior ones, while knowledge in chip design firms is organized in a distributed, specialized network, with lateral flow across multiple and varied nodes. As a result, the importance of “knowing who knows what” is more important in chip design firms and mirrors findings among technical support groups (Das 2003, Pentland 1992) and scientists (Borgatti and Cross 2003). These findings may have additional implications for understanding how firms acquire new knowledge. Based on the patterns of dyadic exchange across all engineers in chip design workplaces and the role of each engineer as an expert in some area(s), one would expect, for example, that new knowledge can enter chip design firms through any engineer. By contrast, in structural engineering workplaces, the paucity of instances in which junior engineers teach seniors implies that new knowledge primarily enters these firms through senior engineers. Overall, our results suggest that knowledge-based theories of the firm ought to draw on the learning models that apply in the workplace.

Although all of the individuals we observed were engineers, the two models of workplace learning differed considerably, as we have discussed. One noteworthy similarity that we have not yet addressed is that learning in both occupations occurred primarily via dyadic exchanges, constituting nearly three-fourths of all learning instances in each occupation. The predominance of dyadic exchanges challenges Lave and Wenger’s (1991) idea that learning occurs in a community of practice with no strong importance attached to dyadic relationships. In light of the importance that researchers have placed on communities of practice in issues of learning and knowledge (Gittleman and Kogut 2003, Boland and Tenkasi, 1995, Brown and Duguid 1991),
the predominance of dyadic exchanges among engineers warrants further investigation of the
nuanced role of the community of practice and its component parts.

Other studies provide similar evidence that calls into question the strong role of the
community of practice. Bucher and Stelling (1977) reported strong dyadic ties between residents
in a psychiatric program and their supervisors. These students reviewed their progress with a
patient to the same supervisor each week and did not shop around for advice among other
supervisors. Similarly, Hutchins (1993), in his account of learning how to navigate amphibious
helicopter transports, reported primarily dyadic exchanges. Some scholars, however, observed
that in fields that include medicine, high steel ironworking, and photocopier repair, the
newcomer frequently learned in group settings in which he was instructed by one or more senior
colleagues (Orr 1996, Bosk 1979, Haas 1977). These mixed findings prompt a final question:
What other forms of workplace learning might exist and under what conditions might a given
model apply?

Beginning with the social nature of the exchange, one might explain the prevalence of dyadic
exchanges in structural engineering on the basis of the master-apprentice relationships we found
there, which were reinforced by the vertical organization of knowledge. In chip design, dyadic
relationships assumed a structure that mapped the knowledge network within the firm onto role
and project assignments. Learning and knowledge involved all the engineers within each firm,
but dyadic exchanges governed the way in which learning occurred and skills and knowledge
were transferred. Knowledge may be organized in different ways in other occupations and thus
necessitate more group learning or self-learning than what we observed in these two fields.

Beyond the social nature of learning exchanges, models of learning may also vary in terms of
which individuals primarily learn and teach, who initiates learning, and the methods by which
knowledge is transferred. For example, another model of learning could feature mostly tutoring of newcomers in group-learning situations initiated by the newcomers and emphasizing knowledge transfer from a senior person. Our data suggest a few factors that might shape the form of learning that would characterize each setting. The subject of the knowledge gained appears to be a major factor: In the two engineering occupations we studied, the combined total of learning about technical content, procedures, and tools accounted for most learning (98% of learning instances in chip design, and 85% in structural engineering). This similarity in the subject of learning may explain why dyadic exchanges dominated in both models we observed; possibly, these subjects are best taught one-on-one as individuals hover over tools and materials. The form of learning also may be strongly shaped by factors related to product, technology, and environment. Additionally, purely historical events peculiar to a specific occupation, such as efforts to gain legitimacy as a profession, may figure prominently in determining the model of workplace learning. A future theory of workplace learning might account for the many determinants of the form of learning and with them predict which form will apply for each occupation.
References


### Table 1. Summary of Findings on Learning Across Two Engineering Occupations

<table>
<thead>
<tr>
<th>Nature of Exchange</th>
<th>Structural Engineers</th>
<th>Chip Designers</th>
<th>Structural Engineers</th>
<th>Chip Designers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyadic</td>
<td>72%</td>
<td>75%</td>
<td>Junior Teaching Junior</td>
<td>27%</td>
</tr>
<tr>
<td>Group</td>
<td>23%</td>
<td>8%</td>
<td>Junior Teaching Mid-Level</td>
<td>2%</td>
</tr>
<tr>
<td>Self</td>
<td>5%</td>
<td>17%</td>
<td>Junior Teaching Senior</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>Junior Teaching Others</td>
<td>2%</td>
</tr>
<tr>
<td>Mid-Level Teaching Junior</td>
<td>27%</td>
<td>30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group (mixed rank)</td>
<td>7%</td>
<td>7%</td>
<td>Senior Teaching Junior</td>
<td>50%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>Others Teaching Junior</td>
<td>4%</td>
</tr>
</tbody>
</table>

### Knowledge Flow in Dyadic Exchanges Involving Juniors

<table>
<thead>
<tr>
<th>Who Was the Learner</th>
<th>Structural Engineers</th>
<th>Chip Designers</th>
<th>Knowledge Flow in Dyadic Exchanges Along the Hierarchy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior</td>
<td>69%</td>
<td>43%</td>
<td>Junior to Mid-Level</td>
</tr>
<tr>
<td>Mid-Level</td>
<td>16%</td>
<td>26%</td>
<td>Mid-Level to Junior</td>
</tr>
<tr>
<td>Senior</td>
<td>2%</td>
<td>9%</td>
<td>Junior to Senior</td>
</tr>
<tr>
<td>Group (mixed rank)</td>
<td>7%</td>
<td>7%</td>
<td>Senior to Junior</td>
</tr>
<tr>
<td>Other</td>
<td>5%</td>
<td>14%</td>
<td>Total</td>
</tr>
</tbody>
</table>

### Knowledge Flow in Dyadic Exchanges Along the Hierarchy

<table>
<thead>
<tr>
<th>Structural Engineers</th>
<th>Chip Designers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior to Mid-Level</td>
<td>17%</td>
</tr>
<tr>
<td>Mid-Level to Junior</td>
<td>83%</td>
</tr>
<tr>
<td>Junior to Senior</td>
<td>4%</td>
</tr>
<tr>
<td>Senior to Junior</td>
<td>96%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Learning Mode

<table>
<thead>
<tr>
<th>Teacher in Group Exchanges</th>
<th>Structural Engineers</th>
<th>Chip Designers</th>
<th>Knowledge Flow in Group Exchanges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior</td>
<td>7%</td>
<td>17%</td>
<td>Junior to Mid-Level</td>
</tr>
<tr>
<td>Mid-Level</td>
<td>0%</td>
<td>17%</td>
<td>Mid-Level to Junior</td>
</tr>
<tr>
<td>Senior</td>
<td>77%</td>
<td>56%</td>
<td>Senior Teaching Junior</td>
</tr>
<tr>
<td>Mixed Group</td>
<td>4%</td>
<td>6%</td>
<td>Others Teaching Junior</td>
</tr>
<tr>
<td>Others</td>
<td>11%</td>
<td>6%</td>
<td>Total</td>
</tr>
</tbody>
</table>

### Who Initiated Instances of Junior Learning

<table>
<thead>
<tr>
<th>Structural Engineers</th>
<th>Chip Designers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior to Mid-Level</td>
<td>17%</td>
</tr>
<tr>
<td>Mid-Level to Junior</td>
<td>83%</td>
</tr>
<tr>
<td>Junior to Senior</td>
<td>4%</td>
</tr>
<tr>
<td>Senior to Junior</td>
<td>96%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Subject of the Learning Instance

<table>
<thead>
<tr>
<th>Structural Engineers</th>
<th>Chip Designers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Content</td>
<td>54%</td>
</tr>
<tr>
<td>Organizational Factors</td>
<td>2%</td>
</tr>
<tr>
<td>Political Factors</td>
<td>13%</td>
</tr>
<tr>
<td>Procedures</td>
<td>21%</td>
</tr>
<tr>
<td>Tools</td>
<td>10%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>