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Individual Experience and Experience Working Together: Predicting Learning Rates from Knowing Who Knows What and Knowing How to Work Together

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Learning by doing represents an important mechanism through which organizations prosper. Some firms, however, learn from their experience at a dramatic rate, while other firms exhibit very little learning at all. Three factors have been identified that affect the rate at which firms learn: (a) the proficiency of individual workers, (b) the ability of firm members to leverage knowledge accumulated by others, and (c) the capacity for coordinated activity inside the organization. Each factor varies with a particular kind of experience. An increase in cumulative individual experience increases individual proficiency. An increase in cumulative organizational experience provides individuals with the opportunity to benefit from knowledge accumulated by others. An increase in cumulative experience working together promotes more effective coordination and teamwork. To gain insight into factors responsible for the learning curve, we examine the contribution of each kind of experience to performance, while controlling for the impact of the other two. The study context is a teaching hospital. The task is a total joint replacement procedure, and the performance metric is procedure completion time. We find that each kind of experience makes a distinct contribution to team performance. We discuss the implications of our findings for the learning-by-doing framework in general, and learning in the team context in particular.

Key words: experience-based learning; learning by doing; organizational learning; social networks; transactive memory systems
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Introduction

Performance typically increases as organizations gain production experience. These "learning curves" have been found in many organizations in different industries. For example, the unit costs of producing aircraft (Alchain 1963, Benkard 2000, Wright 1936), ships (Rapping 1965), trucks (Argote and Epple 1990), and semiconductors (Hatch and Mowery 1998) have been shown to follow a learning curve: The cost of producing a unit of each product decreased at a decreasing rate as production experience was acquired. Not only has evidence of organizational learning been found in manufacturing, it has also been found in service settings. For example, complication rates in new surgical procedures (Kelsey et al. 1984) and surgical procedure completion times (Pisano et al. 2001) have been shown to follow a learning curve.

Although there is considerable evidence in support of the learning-curve framework, organizations vary dramatically in the rate at which they learn from experience (Dutton and Thomas 1984). Pisano et al. (2001) and Edmondson et al. (2003) demonstrated this variation in learning rates across hospitals performing a new cardiac procedure. Further, based on qualitative evidence at each hospital, the researchers (Edmondson et al. 2001) suggested factors that might explain the variation, such as the stability of team membership and the quality of communication among team members.

With so much variation in learning outcomes, more recent research has shifted towards explaining variation in learning rates (Adler and Clark 1991, Argote 1999, Haunschild and Sullivan 2002, Ittner et al. 2001, Lapre and Van Wassenove 2001, Lieberman 1987, Pisano 1994, Terweisch and Bohn 2001). Prior work has identified several factors that affect the rate at which organizations benefit from their own experience (see Argote et al. 2003 for a recent review). The importance of three factors is highlighted. One factor is the proficiency of individual workers. Worker proficiency can vary with the amount of turnover in the organization (Carley 1992), with how experienced individual workers are (Shafer et al. 2001), and with how much those workers have forgotten (Bailey 1989). Another factor is how much individuals benefit from knowledge accumulated by others. The ability of individuals to use knowledge accumulated by their colleagues turns on the rate of knowledge transfer inside the organization. Knowledge transfer can take the form of individual mobility or it can result from the transfer of more efficient routines and practices across organizational units (Baum and Ingram 1998, Darr et al. 1995, Epple et al. 1991, Hatch and Mowery 1998, Lapre and Van Wassenhove 2001, Zander and Kogut 1995). The third factor is the ability of organizational members to coordinate their activity. Improvements in coordination could result from better layout and material flow, or from individuals training and working together and learning who knows what and how to trust each other and coordinate their activities (Liang et al. 1995; Moreland et al. 1996; Uzzi 1996; Edmondson et al. 2001, 2003).

Each factor varies with a particular kind of experience. Individual experience—the cumulative production history of any one individual—provides an individual with an opportunity to become more proficient at his or her tasks and at performing established routines and practices. Organizational experience—the cumulative production history of the organization—provides the organization with the opportunity to identify more productive routines and practices. As the organization gains more experience, each individual has more opportunities to benefit from knowledge accumulated by others. Experience working together—the cumulative production history of pairs of individuals—provides individuals with the opportunity to learn who knows what, resulting in a more efficient division of labor. And, with increased experience working together, individuals become more willing to share knowledge and information, increasing their ability to coordinate across their specialized roles.

We examine the contribution of each kind of experience to performance. By considering how much each kind of experience affects performance while assessing the effect of the other two, this research provides a more comprehensive test of the mechanisms that underlie variations in learning outcomes. The structure of this paper is as follows. We start with a description of the research setting and why we expect experience to influence learning outcomes. Next, we develop our theoretical predictions about the effects of each kind of experience on performance. We draw on literature on the social psychology of small groups as well as literature on social networks to develop our theoretical predictions. Finally, we test those predictions among surgical teams that perform total joint replacements, a context where experience has been shown to improve organizational outcomes (Katz et al. 2001).

The Research Context

The focal organization is an orthopedic department at a large nationally ranked teaching hospital. The residency program is one of the best programs in the country. The program has two primary goals. The first goal is to provide quality patient care. The second goal is to train outstanding surgeons. The goals are complementary. While surgeons are refining and applying their knowledge of established surgical routines to increase the quality of patient care, they are training residents, who learn by doing. While residents are learning established surgical routines, they are also learning the idiosyncratic approach of each surgeon and, therefore, how to work with that particular surgeon and with each other.

The task is a total joint replacement procedure. We focus on two kinds of joint replacements: a total knee replacement (TKR) and a total hip replacement (THR). Both a TKR and a THR are major surgical procedures that involve replacing the original joint with an artificial joint. A TKR or a THR could occur for one of several reasons, but the most common reason is severe arthritis, basic wear and tear, which causes degeneration of the joint. While the indication to replace a knee or a hip is often the same, each surgical procedure is distinct. The knee is a hinge joint, providing motion where the femur (thigh) meets the tibia (lower leg). During a TKR, the ends of the femur and tibia are removed. The end of the femur is replaced with a metal shell. The end of the tibia is replaced with a channeled plastic piece that has a metal stem. The hip is a ball and socket joint, where the socket is the "cup-shaped" bone of the pelvis and the ball is the head of the femur. During a THR, the socket is replaced with a plastic cup socket and the ball is replaced by a metal ball and stem that is inserted into the femur. During the study period, the hospital performed 491 THRs and 660 TKRs. Our performance metric is the amount of time it takes for a surgical team to complete a total joint replacement.

A total joint replacement provides an excellent opportunity to study learning by doing. Total joint replacements have been performed for over 40 years. During that time standard surgical routines and techniques have been established. Experience should improve how well a doctor performs a total joint replacement. First, an increase in individual experience provides a surgeon with the opportunity to become more proficient performing established routines and to tailor those routines to his or her skills and abilities. Second, a total joint replacement can be performed using one of many established routines. For example, there are two basic kinds of artificial joints. Some artificial joints are held in place by "cement." For others, the artificial joint is held in place by a bone graft. Moreover, a large number of firms manufacture total joints. Each total joint can have a distinct surgical routine. Given the amount of legitimate variation in terms of how a total joint replacement could be performed, knowledge accumulated by others should be valuable. For example, instead of experimenting with each surgical routine, a surgeon can draw on the experiences of his or her colleagues. Third, a total joint replacement is performed in the team context. Experience working with others should improve performance. Each surgeon can have his or her own idiosyncratic approach to a joint replacement, including using different surgical instruments. The more knowledge that surgeons have about who knows and does what, the more productive the team should be.

Individual Experience: Individual Knowledge

A long tradition of research in psychology examines the effect of individual experience on task performance (Thorndike 1898, Newell and Rosenbloom 1981, Delany et al. 1998). The results of these studies indicate the time individuals take to complete a task, and the number of errors they make decreases at a decreasing rate as individuals gain experience with the task. The tasks used in this line of work were individual tasks such as typing (Thurstone 1919) or learning lists of words.

A total joint replacement is performed in the team context. Individual experience is important, however, even in the team context. While working in the team context, individuals have the opportunity to accumulate knowledge about the task and the different roles that they can perform during the surgical procedure. As the individual learns more about the different roles, he or she becomes more proficient in performing each role. Our indicator of individual knowledge is the average number of times that an individual team member has performed either a THR or a TKR. As the average level of individual experience inside the team increases, we expect performance to improve. Thus, we predict that:

Hypothesis 1. *Individual experience reduces procedure completion time.*

Organizational Experience: Knowledge Accumulated by Others

Organizational experience is important because it provides each member of the organization with the opportunity to master established routines and practices, and it provides individuals with the opportunity to learn how to work together. However, organizational experience is important for a third reason. Organizational experience provides individuals with the opportunity to benefit from knowledge accumulated by others. Trial and error is an important mechanism through which people learn. Repeating a task multiple times provides a person with the opportunity to experiment with multiple routines and practices. Some routines and practices prove to be more effective than others. Members of an organization accumulate knowledge faster than the same number of individuals working alone because physical and psychological proximity affect the rate of knowledge transfer from one person to the next. Members of the same organization are likely to share knowledge and information with each other. Working in close proximity provides people with the opportunity to learn by observation. The experience of others represents a pool of knowledge at an individual's disposal that is distinct from the knowledge he or she has accumulated directly.

An increase in cumulative organizational experience should have a positive effect on how well surgical teams perform total joint replacements. When the level of organizational experience is high, the team members do not have to experiment with every surgical routine to learn which routines work best. Team members can leverage the knowledge accumulated by their colleagues. As the overall level of knowledge available in the organization increases, we expect that performance will improve. Thus, we predict that:

Hypothesis 2. *Organizational experience reduces procedure completion time.*

Experience Working Together: More Effective Teamwork

Given that a total joint replacement is an interdependent task that requires coordination, experience working together should be valuable. Researchers who study experience working together provide two distinct explanations for why such experience improves performance. Each explanation highlights the ability of individuals to coordinate their activity. The explanations, however, emphasize different mechanisms responsible for improved coordination. For example, researchers who study group dynamics emphasize the importance of knowing "who knows what." Teams composed of individuals who have experience working together have a more accurate and shared sense of who knows what on the team (Faraj and Sproull 2000; Larson et al. 1996; Lewis 2003; Moreland et al. 1996; Wegner 1986, 1995). Knowledge of who knows what is important because it promotes the development of a more effective division of labor (Liang et al. 1995). Effective teamwork results from identifying the right roles and responsibilities and assigning the most knowledgeable person to each role.

Researchers who study experience working together in the market context emphasize the importance of transaction partners learning how to govern their interaction. Multiple exchanges increase the likelihood of trust (Uzzi 1996), and trust promotes the exchange of "private" knowledge and information (Uzzi and Lancaster 2003). Sharing private knowledge provides transaction partners with the opportunity to learn how to govern their relationship. Instead of being governed by the market, the transaction is governed by a relationship-specific logic and terms of trade (Uzzi 1997). Researchers in this tradition emphasize the importance of relationship-specific heuristics, the knowledge embedded in the tie that connects people performing distinct roles. Effective coordination results from actors performing distinct roles learning how to coordinate their activity.

The two explanations for why experience working together improves coordination complement each other. Knowing who knows what is critical for defining roles and responsibilities inside the team and for assigning the most competent person to each role. However, this is only one half of effective coordination. The other half turns on the development of relationship-specific heuristics that enhance how well people performing distinct roles interact with each other. Effective teamwork is a function of identifying the most appropriate roles for completing a task, assigning the right people to those roles, and enabling people who occupy distinct roles to coordinate their activity.

We expect experience working together to improve how well a team performs a total joint replacement procedure. With more experience working together, physicians have a better sense of how to divide their labor and how to coordinate their behavior. To test this hypothesis, we calculate the number of times that team members have completed a surgical procedure together. We call this variable team experience. An increase in team experience is expected to have a positive impact on team performance. Thus, we predict:

Hypothesis 3. *Team experience reduces procedure completion time.*

Methods and Measures

Data for our analysis come from two archival sources. The first is a surgical note. Each surgical note contains duration data and information about which physicians were involved in the procedure. This note is used to construct our dependent and key independent variables. The second data source is an operative note. Data from this source are used to construct important control variables. The operative note contains information on the preoperative diagnosis, including a discussion of numerous confounding factors such as pathology, childhood disease, or trauma that could affect the length of the procedure, as well as information about the patient's age and gender.

Independent and Dependent Variables

Dependent Variable, Procedure Completion Time. We use reductions in procedure time as an indicator of organizational learning. A long tradition of research in psychology has examined reductions in the time required to perform a task as an indicator of learning (Thorndike 1898, Thurstone 1919, Graham and Gagne 1940). Research in manufacturing has tended to focus on labor costs, which can also be thought of as project completion time. For example, in their analysis of truck manufacturing, Epple et al. (1991, 1996) found that, holding the number of labor hours constant, each increase in organizational experience had a positive effect on the number of vehicles manufactured during a shift, which indicates that workers took *less time* to manufacture each vehicle. Researchers examining organizational learning in the context of performing surgical procedures have also relied on reductions in procedure time as an indicator of learning (Pisano et al. 2001, Edmondson et al. 2003). In our sample, procedure completion time has a mean of 3.6 hours with a standard deviation of 1.3. The minimum procedure completion time is 28 minutes and the maximum is 11.5 hours. Procedure completion time has a skewed distribution. Given the distribution of completion times, we take the natural log of completion times as our dependent variable.

Consistent with prior research, we assume that faster completion times indicate learning. However, faster completion times could also reflect inattention to the quality of patient outcomes. While this concern is valid, it seems unwarranted in the current context. Past research indicates that experience improves the quality of patient outcomes (Katz et al. 2001). Second, faster completions can improve the quality of patient outcomes (Pisano et al. 2001). Third, while we do not have data on patient outcomes, we do have data on several factors that should affect those outcomes. Holding experience constant, factors that make a surgical procedure more difficult to complete should, on average, require more time to maintain the quality of patient outcomes. We control for two factors that make a total joint replacement more difficult to compete—case severity and the number of confounding factors, such as trauma and deformities. Both factors slow procedure completion times, indicating that surgeons are concerned with the quality of patient outcomes.

Organizational Experience. The data are a time series, so we can calculate the number of times that a kind of procedure has been performed prior to the focal operation. The cumulative number of operations is an indicator of the amount of knowledge available at the hospital. The cumulative experience variable is procedure specific. For a TKR, for example, the organizational experience variable would indicate the number of times that a TKR has been performed at the hospital prior to the current procedure.

Individual Experience. For each person involved in a procedure, we calculate the number of times that he or she has performed the procedure, not including the current procedure. This variable is IK_i. We sum across these individual values and divide by team size to define the level of individual knowledge on the team, $\sum_{i=1}^{N} IK_i/N$, where N is number of people on the team. The variable indicates the amount of individual knowledge available to the team.

Our prediction for organizational experience relates team performance to the knowledge accumulated by people *outside* the focal surgical team. Our organizational experience includes the cumulative experience of people on the focal team. To test our prediction for organizational experience, we subtract the cumulative experience of individuals *inside* the focal team from cumulative organizational experience. While we expect both individual and organizational experience to be important, past research generally distinguishes between the two. In addition, the evidence indicates that while both kinds of experience improve performance, focal units benefit from their own experience more than they benefit from knowledge accumulated outside their unit (Argote et al. 1990, Baum and Ingram 1998).[1]

Team Experience. For each pair of individuals on a team, we calculate the number of times that the pair has performed the procedure with each other in the past, not including the current procedure. This variable is RK_{ij}. We sum across pairs on the team and divide by the possible number of pairs to define the level of relationship-specific knowledge available to the team, $\sum_{i=1}^{N}\sum_{j=1}^{N} RK_{ij}/N(N-1)/2$, where N is team size and RK_{ij} is the number of times that person i has operated with person j. The variable indicates the average amount of experience that team members have working with each other.

Although we call our indicator of individual knowledge "individual experience," it is important to be clear about what the variable is not. Individual experience is not the number of times that each team member has performed a procedure by himself. A total joint replacement is an interdependent task, and knowledge is accumulated while working with other people. In a perfect design, we would have knowledge accumulated while working alone and knowledge accumulated while working with others. We could then examine the association between each kind of knowledge and performance. However, given how knowledge is accumulated, our analytical strategy is to estimate the effect that individual (the number of times the individual performed the procedure) experience has on team performance. That individual experience could have been accumulated while working with people on the current team or with people outside the team. The team experience effect, therefore, indicates the additional effect that experience working together has on team performance.

Control Variables

We have two kinds of joint replacements: a total knee replacement (TKR) and a total hip replacement (THR). To control for potential differences between a TKR and a THR, *hip* is a dummy variable set equal to 1 if the surgical procedure is a THR. Some patients are having the original joint replaced, whiles others are having a replacement revised. To control for possible differences between the two kinds of procedures, *revision* is a dummy variable set equal to 1 if the replacement is a revision.

In addition to characteristics of the procedure, models to be presented control for patient background characteristics. *Age* is a continuous variable indicating the patient's age in years. *Male* is a dummy variable set equal to 1 if the patient is male.[2] Arthritis is the primary reason that a joint is being replaced. Some cases of arthritis are more severe than others. Severity could make the procedure more difficult, so we control for level of severity in our analysis. *Severe* is set equal to 1 if the patient has a severe case of arthritis. An even more severe case of arthritis is a tumor. *Tumor* is a dummy variable set equal to 1 if the patient has a tumor. Therefore, the excluded category in this analysis is arthritis.

A patient could have a previous medical condition that could affect the duration of the operation. These conditions are known as confounding factors. Across the cases, five confounding factors are observed: pathology, childhood disease, trauma, previous arthroplasty, and a deformity (mechanical or structural). *Number of confounds* is a count of the number of confounds discussed in the operative note. An alternative specification is to introduce an indicator variable for $n-1$ confounds. Both specifications lead to the same substantive conclusions, so we focus on the more parsimonious approach.

Complication is an indicator variable set equal to 1 if a complication occurred during the procedure. Complications are rare. Only 10% of the cases have a complication, and an even smaller proportion of those complications require repair. For example, only 0.2% of the cases have a complication that requires repair.

Team size indicates the number of physicians (e.g., surgeons, residents, or fellows) involved in a procedure. Teams vary in size from two to four. We control for team size for two distinct reasons. First, team size can affect performance, but the direction of that effect is unclear. For example, bigger teams have access to

[1] Results lead to the same substantive conclusions if we do not remove individual experience from organizational experience. We distinguish focal from nonfocal experience to be consistent with past research and because it provides a more accurate test of our predictions.

[2] The patient background data are not complete. Values for missing data are imputed using NORM version 2.03 created by J. L. Schafer.

more resources, which can have a positive effect on their performance. However, larger teams can find it more difficult to coordinate their behavior. Second, our experience variables covary with team size. Team experience is generally a negative function of size because it is less likely that members of a large team will have operated with each other in the past.

Team tenure is the average tenure of team members. Tenure is defined as the number of years since the physician graduated from medical school. Tenure is a broad indicator of experience. An individual who has been out of medical school for a period of time has more professional experience. Some of that time is spent in residency, doing research, or in a fellowship. As the average team tenure increases, professional experience grows, which should result in a more productive team.

Finally, the surgical procedures are performed over a five-year time period. To control for unobserved year differences, models to be presented include indicator variables for the first four academic years. The fifth academic year is the baseline category.

Results

Descriptive statistics and correlations are provided in Table 1. The baseline correlations in Table 1 provide initial support for our predictions. Procedure completion time has a negative correlation with each experience variable. That is, an increase in experience of any kind is associated with a reduction in procedure completion time.

The classic experience or learning curve is log-linear. A generalization of that model can include squared terms (Epple et al. 1991). We checked to see if the squared terms for any of our experience variables were significant. The squared term for individual experience was. Therefore, the models that we present include a squared term for individual experience. In addition, the observations in our analysis define a time series. To control for serial correlation among operations performed close in time, our model includes an $AR(1)$ covariance structure. The functional form of our performance equation is

$$\begin{aligned}
&\ln(\text{procedure completion time}_t)\\
&\quad = \beta_0 + \beta_1 \ln(\text{organizational experience}_{t-1})\\
&\qquad + \beta_2 \ln(\text{individual experience}_{t-1})\\
&\qquad + \beta_3 (\ln(\text{individual experience}_{t-1}))^2\\
&\qquad + \beta_4 \ln(\text{team experience}_{t-1}) + \beta_5 \text{controls} + u_t,\\
&\qquad\qquad \text{where } u_t = \rho u_{t-1} + e_t. \quad (1)
\end{aligned}$$

Given that our sample contains individuals and teams, we considered using a hierarchical linear model (HLM) (Raudenbush and Bryk 1986, Bryk and Raudenbush 1992). HLM is appropriate when the units of analysis are nested within higher units of analysis and dynamics at the higher level influence outcomes at the lower level (Hofmann and Gavin 1998, pp. 624–626; Nezlek and Zyzniewski 1998, p. 314). Schools are the classic example. Students are nested within schools and the performance of each individual student is a function of his or her characteristics and characteristics of the school. HLM does not appear to be appropriate. We do not have a distinct set of teams within which individuals are nested. Instead, we have a set of teams with overlapping membership, which appears to be a violation of a key assumption in the HLM framework. Moreover, we are not modeling the performance of individual team members. Our performance metric is at the team level of analysis.

Given the structure of our data and the level of our performance outcome, we estimated our performance equation using ordinary least-squares regression. The results are illustrated in Table 2. Predictors are introduced across columns in Table 2 in a stepwise fashion. The control variables are introduced in the first column and the experience variables are added in subsequent columns. The complete model is in Column V. The relationships between the control variables and procedure completion times are reasonable. Procedures performed on males take somewhat longer than those performed on females. Hip replacements generally take longer to complete than knee replacements. Revisions and procedures on patients with tumors or confounding conditions require more time to complete. The effect of tenure, or the average time since physicians completed medical school, is nonmonotonic. Increases in tenure are initially associated with longer procedure time; after approximately five years, however, increases in tenure are associated with decreases in procedure completion time.

Results are generally stable across the columns, so we focus on the results in Column V. The estimates in Column V indicate that each kind of experience impacts procedure completion time. The coefficients in the model represent the change in procedure completion time as each kind of experience increases. The effect for organizational experience is -0.042.[3] As

[3] Our organizational experience effect does not vary in a cross section of organizations. It varies in a single organization over time (Epple et al. 1991, Benkard 2000). Although experience accumulates in a single organization over time, the observed organizational experience effect reflects more than the passage of time. Models in Table 2 include fixed year effects. We estimated three additional models to control for time. First, we replaced the year dummies with calendar time (the number of days that elapsed since the beginning of the observation window). The estimate for organizational experience equaled -0.042 ($p < 0.001$), very similar to the effect for organizational experience in Table 2. Second, we replaced our organizational experience variable with calendar time. If our experience variable reflects the passage of time, we would expect for calendar time to have an effect that is similar to the effect that we observed for organizational experience. The estimate for

Table 1 Descriptive Statistics

	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) Duration+	1.49	0.248																	
(2) Year 1	0.410	0.492	0.020																
(3) Year 2	0.328	0.469	0.012	−0.584															
(4) Year 3	0.152	0.360	−0.045	−0.354	−0.297														
(5) Year 4	0.075	0.264	0.002	−0.238	−0.200	−0.121													
(6) Age	64.750	15.35	−0.026	0.039	−0.015	−0.074	0.036												
(7) Male	0.391	0.488	0.084	−0.073	−0.004	0.044	0.046	−0.002											
(8) Hip	0.426	0.494	0.372	0.043	0.032	−0.000	−0.113	−0.195	0.020										
(9) Revision	0.217	0.412	0.386	−0.003	0.080	0.033	−0.127	0.017	0.000	0.184									
(10) Tumor	0.017	0.130	0.173	0.024	−0.064	0.017	0.012	−0.080	0.002	0.087	−0.005								
(11) Severe	0.320	0.466	−0.146	0.031	−0.028	0.039	−0.048	−0.090	−0.055	0.006	−0.330	−0.091							
(12) Number of confounds	0.419	0.562	0.296	0.026	0.050	−0.012	−0.108	−0.060	−0.023	0.202	0.461	0.160	−0.125						
(13) Complication	0.900	0.298	−0.003	0.046	0.027	−0.053	−0.059	0.094	−0.019	−0.066	−0.065	0.044	0.202	0.226					
(14) Team size+	0.823	0.194	0.050	−0.066	0.053	−0.102	0.122	0.006	0.035	−0.093	0.015	−0.061	−0.031	−0.024	0.012				
(15) Team tenure+	2.380	0.363	−0.076	0.028	0.023	−0.134	0.011	0.059	−0.010	0.068	−0.076	0.011	−0.016	−0.027	0.050	−0.369			
(16) Org. experience+	5.060	1.000	−0.067	−0.734	0.267	0.315	0.316	−0.037	0.081	−0.003	−0.073	0.031	−0.022	−0.060	−0.040	0.003	−0.023		
(17) Individual experience+	3.110	1.160	−0.096	−0.518	0.407	0.257	−0.065	0.015	0.021	−0.155	0.067	−0.121	0.060	0.007	0.062	0.039	−0.143	0.492	
(18) Team experience+	1.480	1.050	−0.126	−0.057	0.234	−0.014	−0.205	0.017	−0.033	−0.088	0.062	−0.135	0.080	0.036	0.037	0.011	−0.029	−0.026	0.519

Notes. $\rho >= |0.057| = p < 0.05$.
$^{+}$ = logged values.

Table 2 Learning Outcomes

Predictors	(I) Controls	(II) Organizational experience	(III) Individual experience	(IV) Individual experience	(V) Team experience	(VI) Unknown individual experience	(VII) Unknown individual and team experience	(VIII) Unknown experience and unequal spacing
Constant	0.531 (0.248)*	0.804 (0.262)*	0.582 (0.279)*	0.509 (0.280)$^{+}$	0.519 (0.279)$^{+}$	0.871 (0.298)*	1.184 (0.377)*	0.979 (0.469)*
Year 1	−0.037 (0.039)	−0.107 (0.044)*	−0.100 (0.044)*	−0.128 (0.045)*	−0.115 (0.045)*	0.028 (0.047)	0.026 (0.060)	0.028 (0.058)
Year 2	−0.051 (0.040)	−0.078 (0.040)*	−0.058 (0.041)	−0.060 (0.040)	−0.056 (0.040)	0.077 (0.042)$^{+}$	0.167 (0.049)*	0.169 (0.048)*
Year 3	−0.076 (0.042)$^{+}$	−0.093 (0.042)*	−0.074 (0.042)$^{+}$	−0.065 (0.042)	−0.070 (0.042)$^{+}$	0.025 (0.041)	0.050 (0.046)	0.051 (0.045)
Year 4	0.019 (0.044)	0.016 (0.044)	0.016 (0.044)	0.018 (0.043)	0.014 (0.043)	0.063 (0.039)	0.039 (0.042)	0.039 (0.041)
Age/100	0.037 (0.040)	0.038 (0.040)	0.040 (0.040)	0.043 (0.040)	0.041 (0.040)	0.016 (0.041)	−0.094 (0.058)$^{+}$	−0.100 (0.058)$^{+}$
Male	0.036 (0.012)*	0.037 (0.012)*	0.037 (0.012)*	0.036 (0.012)*	0.035 (0.012)*	0.033 (0.011)*	0.035 (0.016)*	0.036 (0.016)*
Hip	0.115 (0.014)*	0.118 (0.014)*	0.112 (0.014)*	0.110 (0.014)*	0.111 (0.014)*	0.023 (0.032)	0.057 (0.037)	0.057 (0.037)
Revision	0.073 (0.024)*	0.066 (0.024)*	0.071 (0.024)*	0.073 (0.024)*	0.074 (0.024)*	0.070 (0.023)*	0.063 (0.036)$^{+}$	0.063 (0.036)$^{+}$
Revised hip	0.182 (0.030)*	0.187 (0.029)*	0.184 (0.029)*	0.180 (0.029)*	0.177 (0.029)*	0.161 (0.028)*	0.158 (0.042)*	0.159 (0.042)*
Tumor	0.247 (0.047)*	0.255 (0.047)*	0.237 (0.048)*	0.237 (0.048)*	0.229 (0.048)*	0.144 (0.057)*	0.214 (0.074)*	0.212 (0.074)*
Severe	−0.010 (0.014)	−0.012 (0.014)	−0.009 (0.014)	−0.006 (0.014)	−0.005 (0.014)	0.004 (0.013)	0.003 (0.019)	0.005 (0.019)
Number of confounds	0.042 (0.012)*	0.041 (0.012)*	0.041 (0.012)*	0.043 (0.012)*	0.044 (0.012)*	0.050 (0.012)*	0.047 (0.017)*	0.049 (0.017)*
Complication	0.017 (0.021)	0.018 (0.021)	0.022 (0.021)	0.018 (0.021)	0.016 (0.021)	0.005 (0.020)	−0.067 (0.030)*	−0.067 (0.030)
Team size	0.057 (0.034)$^{+}$	0.045 (0.034)	0.045 (0.034)	0.048 (0.034)	0.049 (0.034)	0.055 (0.034)	0.138 (0.062)*	0.144 (0.061)*
Team tenure	0.703 (0.198)*	0.659 (0.198)*	0.845 (0.214)*	0.911 (0.215)*	0.914 (0.214)*	0.420 (0.228)$^{+}$	0.267 (0.278)	0.395 (0.034)
Team tenure^2	−0.151 (0.040)*	−0.143 (0.039)*	−0.181 (0.043)*	−0.193 (0.043)*	−0.193 (0.043)*	−0.076 (0.046)$^{+}$	−0.052 (0.055)	−0.074 (0.066)
Organizational experience		−0.033 (0.010)*	−0.024 (0.011)*	−0.039 (0.012)*	−0.042 (0.012)*	−0.032 (0.014)*	−0.059 (0.020)*	−0.055 (0.019)*
Individual experience			−0.017 (0.007)*	0.047 (0.025)$^{+}$	0.046 (0.025)$^{+}$	0.139 (0.052)*	0.256 (0.061)*	0.253 (0.061)*
Individual experience^2				−0.012 (0.004)*	−0.009 (0.004)*	−0.028 (0.012)*	−0.051 (0.014)*	−0.050 (0.014)*
Team experience					−0.022 (0.007)*	−0.018 (0.007)*	−0.024 (0.010)*	−0.023 (0.010)*
Model fit								
N	1,151	1,151	1,151	1,151	1,151	1,151	580	580
R-squared	0.335	0.341	0.344	0.348	0.353	0.460	0.515	—
Adjusted R-squared	0.325	0.331	0.333	0.337	0.341	0.439	0.476	—
Log-likelihood	204.29	209.22	211.75	215.47	220.04	323.39	179.40	98.1
Model improvement		9.86 ($p < 0.001$)	4.92 ($p < 0.05$)	7.44 ($p < 0.001$)	9.14 ($p < 0.001$)	—	—	—

Notes. Columns include parameter estimates with standard error in parentheses.
$^{+} = p < 0.10$, $^{*} = p < 0.05$.

cumulative organizational experience increases, completion times drop. For example, when the cumulative level of organizational experience is 100 TKRs, the typical TKR takes 18% less time (approximately 34 minutes) to complete. When the cumulative level of organizational experience is 300 TKRs, the typical TKR takes 21% less time (approximately 41 minutes) to complete. That means that a surgical team that performs a TKR later is in a very different position than a team that performs a TKR earlier. Teams that operate later can draw on the experiences of their colleagues, and therefore have more knowledge at their disposal.

The effect for team experience is −0.022. More experienced teams take less time to complete their procedures. For example, a team whose members have performed 10 TKRs together takes 5% less time (approximately 10 minutes) to complete the procedure when compared to a team that has no experience operating together. One team has members that have performed 51 TKRs together. That team takes 8% less time (approximately 16 minutes) to complete the procedure than a team whose members have no experience working together. Our measure of team experience is the average number of times that each pair or dyad on the team has operated together. This measure assumes that more experienced pairs on a team can compensate for less experienced pairs. An alternative team experience measure would count the number of times that everyone on the team has operated together. This measure assumes that the team is only as experienced as the least experienced pair. Team experience based on the average number of times pairs have worked together assumes that knowledge is relationship specific. More knowledge in one relationship can compensate for less knowledge in another. Team experience based on the minimum assumes that knowledge is specific to the whole team. Models in Table 2 were reestimated using the alternative team experience measure. With the exception of one model, team experience based on the average outperformed team experience based on the minimum. The result suggests that coordination is relationship specific, and better coordination in one relationship can compensate for poorer coordination in another relationship.

The individual experience effect is more involved. The effect for individual experience is 0.046 and the effect for individual experience squared is −0.009. The total effect for individual experience has an inverted-U shape. Initial increases in individual experience hamper team performance. At some point, however, continued increases in individual experience begin to reduce procedure completion time. The critical amount of individual experience is approximately five procedures. Individual experience was not predicted to have an inverted-U shape. We offer two explanations for the observed effect. The first centers on the allocation of work. It is possible that as inexperienced team members become more experienced, they take on more demanding roles and responsibilities. However, because these individuals are not the most competent people on the team, performance suffers. As inexperienced individuals become more experienced, their competence level is more in line with the work that they are performing, so team performance starts to improve and continues to improve as inexperienced team members become even more experienced. The second explanation highlights what people learn while working with others. In the current work context, individual knowledge is accumulated while working with other people. Therefore, the knowledge that a person accumulates while performing a total joint replacement has two dimensions, one that is task-based and another that is relationship-based. Each time a person performs a procedure he or she learns something about the task and something about one's colleagues. When working with the same people, both elements of knowledge combine to have a positive effect on team performance. When individual experience is low, a person may not know that he or she is learning two distinct kinds of knowledge or be able to distinguish between the two. Something learned working with one colleague may be inappropriately applied to another colleague who does the procedure differently. However, as the individual gains more experience, he or she becomes more aware of the two kinds of knowledge and learns how to distinguish one from the other. The individual learns how to apply what he or she knows about the task while working with a different set of colleagues. As an individual becomes more experienced, he or she learns that a surgical technique that is effective while working with a particular colleague could be problematic while working with another colleague.

Unknown Experience

We find evidence that is consistent with our predictions, but several issues need to be addressed that can influence confidence in the results. The first issue is unknown experience. Our experience variables are based on the number of times that either a TKR or a THR is performed during the five-year observation period. However, some physicians have operating experience prior to the observation period. Therefore, unknown experience affects the amount of individual knowledge available to a team. The issue is

calendar time was not significant. Finally, if we included all three variables (year dummies, calendar time, and organizational experience), the estimate for organizational experience equaled −0.050 ($p < 0.001$), none of the year dummies were significant, and the estimate for calendar time was not significant as well.

how to adjust for unobserved experience in our analysis. Given the nonmonotonic association between individual experience and procedure completion time, we expect for unknown experience to change the slope for individual experience in our performance equation. The impact that an increase in individual experience has on procedure completion time is conditional on the total amount of individual experience. To adjust for unknown individual experience, we include slope adjustments for different lead surgeon-procedure combinations.[4] There are 28 lead surgeon-procedure combinations. We include 20 lead surgeon-procedure slope adjustments to the model in Column V in Table 2. Our model only includes 20 slope adjustments because if we include more than 20, our correlation matrix is near singular and the model will not estimate. While it would be ideal to include an adjustment for each lead surgeon-procedure combination, our adjustments encompass the physicians who are more likely to have a considerable amount of unknown experience. The 20 slope adjustments are for physicians who perform 89% of the surgical procedures. Any lead surgeon who has performed more than 25 procedures has a slope adjustment in the model, so while not exhaustive, the controls are extensive. The results based on the adjusted individual experience effect are shown in Column VI. The estimates for the experience variables are significant and in the same direction as the estimates in Column V. Thus, our results are robust to adjusting for unknown individual experience.

We also have unknown experience with respect to experience working together. To account for unobserved experience working together, we exclude from our analysis any surgical procedure that includes a resident or fellow who started the program prior to the first year of observation. These individuals account for unknown experience working together. For residents or fellows who entered the program after the first observation year, we have a complete work history. We have complete information on their individual experience and on the amount of experience they have working with others. The estimates from this analysis are in Column VII. Those estimates are comparable to the estimates in Column V.

Because the hospital performed joint replacements before the start of our time series, we also have unknown organizational experience. To deal with the unknown organizational experience, we included a coefficient (z) to capture the organizational experience accumulated at the hospital up to the point when our data begin. Thus, we estimated Equation (1) with the organizational experience variable expressed as (z + organizational experience$_{t-1}$), where z equals the organizational experience accumulated prior to the first observation in our sample. Darr et al. (1995) used a similar approach in their study of franchises because they did not have complete production histories for some of the stores in their sample.

Results allowing for the unknown organizational experience at the hospital are very similar to those already described. The coefficient of the organizational experience variable (-0.066) remains negative, but becomes slightly less significant ($p = 0.052$) when the unknown organizational experience is included than when it is not. The magnitude and significance of individual experience, the square of individual experience, and team experience are virtually identical whether or not the production history before our first observation is treated as an unknown. Thus, our results are generally robust to the specification that takes into account unknown organizational experience.

We also performed sensitivity analysis to determine how sensitive our results were to observations at the beginning of the sample. We can remove up to 100 observations (approximately 10% of the sample) without much change in the magnitude or significance of the coefficient for organizational experience.

Unequal Spacing

The second issue is unequal spacing between the observations. The observations in our analysis define a time series. To control for serial correlation among operations performed close in time, our model includes an $AR(1)$ covariance structure. The conventional time-series model assumes equal spacing between units of analysis. Our procedures are not equally spaced. Spatial covariance structures can be used to model covariance structures in which correlations among observations decline as a function of time (Littell et al. 1996, Zhou 2000). For example, the spatial power function is a direct generalization of the $AR(1)$ structure, but allows unequal spacing among observations. The spatial power function models the covariance between two observations at t_1 and t_2 as $\text{cov}(y_{t1}, y_{t2}) = \sigma^2\rho^{|t1-t2|}$, where ρ is an autoregressive parameter and assumed to satisfy $|\rho| < 1$ and $\sigma^2\rho$ is the overall variance. The unequal spacing assumption could influence our findings, but it does not. The estimates in Column VIII relax the equal spacing assumption and allow the autocorrelation between surgical procedures to vary as a function of time. The covariance structure has the spatial power function just

[4] A lead surgeon is associated with each surgical procedure. The lead surgeon has primary contact with the patient and is responsible for the surgical procedure. The term lead surgeon, however, can be a misnomer in the surgical context. Senior surgeon is more accurate because lead does not designate the role of the surgeon. For example, the lead surgeon could act as an assistant to provide instruction to a resident or a fellow, or the lead surgeon could teach by performing the procedure and allow the fellow or resident to learn by observation.

described above. Like the models that adjust our estimates for unknown experience, adjusting for unequal spacing changes the size of the parameter estimates somewhat, but does not change the conclusions drawn from those estimates.

Discussion and Conclusion

Learning by doing represents an important framework in the study of organizations. Learning curves have been found across a wide variety of organizations. Although there is considerable evidence in support of learning, some organizations exhibit faster learning rates than others. To illuminate factors responsible for the variation in learning rates, we considered how three distinct kinds of experience affect learning and performance. How different kinds of experience impact performance can provide some insight into why some organizations learn faster than others. The focus on more fine-grained indicators of experience is also consistent with recent work on organizational learning (Ingram 2002, Schulz 2002).

Although the results are consistent with our predictions, there are alternative explanations for our findings. The first potential explanation is selection: Surgeons select the most competent team members or the members with whom they work best. According to this explanation, selection rather than learning would drive the performance improvements we observe. This explanation, however, is not viable in the current study context. Members are assigned to surgical services based on a rotation schedule determined at the beginning of the year by the head of the residency program. Members rotate over surgical services every couple of months based on the predetermined schedule. Further, because the hospital wants to maintain its strong reputation as a teaching hospital, it ensures that each resident or fellow performs an adequate volume of procedures to complete their training. Thus, selection is not a viable alternative explanation in this context.

A second potential alternative explanation that we evaluated was whether the severity of the cases was systematically related to our experience measures. For example, perhaps teams selected easier cases to operate on as they gained experience. To investigate this issue, we examined the zero-order correlations between the measures of experience and the measures of case difficulty or severity. The correlations between the experience measures and the measures of case difficulty were mixed (see Table 1). For example, an increase in cumulative organizational experience is associated with an increase in case severity. A tumor is the most severe kind of arthritis. However, as organizational experience increases, the complication rate and the number of confounding factors decline. Further, the relationships between individual experience and the difficulty measures were mixed as well. As individual experience increased, the severity of the cases decreased, while the complication rate and the number of confounding factors increased. A similar pattern holds for team experience. As team experience increased, the severity of patient arthritis declined, but the complication rate and the number of confounding factors increased. Based on this mixed pattern of results, we conclude that the relationship between experience and case difficulty is not systematic. Moreover, the correlations are small in magnitude. None of the correlations were larger than $|0.14|$.

This research makes several contributions to the learning-by-doing framework. Based on our analysis of longitudinal data spanning approximately five years from multiple teams performing surgical procedures in a teaching hospital, we were able to estimate the effects of individual experience, team experience, and organizational experience on reductions in procedure completion time. While previous authors have hypothesized that individual experience and team experience contribute to the performance gains associated with organizational learning, this is the first study to provide empirical evidence on the effect of those factors, above and beyond the effect for organizational experience.

The results also contribute to an understanding of what individuals learn in the team context. The effect for individual experience on team performance had an inverted-U shape. At low levels of individual experience, increasing individual experience hurt procedure completion times. After approximately five procedures, however, continued increases in individual experience were associated with decreases in procedure completion time. We believe that the initial effect of experience on completion time was a form of negative transfer: Individuals inappropriately applied what they learned working with one set of colleagues to a different set. As individuals gain experience, they learn about the task and they learn how to apply what they learn working with one set of colleagues to another set. The effect of their experience on performance then becomes beneficial. In the team context, individuals not only learn the task—they also learn about other people performing the task. Being productive requires an appreciation for each kind of knowledge and the situations when each kind is valuable.

The results also advance our understanding of the factors responsible for effective teamwork. Experience working together was a significant predictor of team performance. We identified two basic mechanisms through which team experience benefits organizational learning outcomes. Members of teams with considerable experience working together have more accurate and more sophisticated knowledge of who knows what on the team than their less-experienced counterparts. This knowledge enables experienced teams to match members with the tasks for which they are most qualified and enables members to know to whom to go for advice on the team. Experience working together also improves coordination by enabling members to anticipate each other's actions and by developing special languages and shorthand ways of communicating (Weber and Camerer 2003). Members of teams with considerable experience working together are also more likely to trust each other than members lacking such experience. Knowing who knows what has been emphasized in the small-groups literature, and relationships-specific knowledge has been emphasized in research on embedded market transactions. We think that effective teamwork depends on both factors. Further research is needed to determine the exact contribution that each mechanism makes to effective teamwork. For some tasks, knowing who knows what will be more (or less) important than the relationship-specific knowledge, while other tasks will require both.

Although each kind of experience represents a distinct kind of knowledge, the different kinds of knowledge can substitute for each other. For example, the goal of the program is to train competent surgeons. Turnover is expected. However, turnover in the program reduces the level of individual and team experience inside the organization. The decline in knowledge can be expected to hurt performance. The results indicate, however, that the loss in knowledge due to this turnover can be compensated for in part by how future teams are constructed. Teams should contain at least three individuals, two individuals who are experienced and have experience working with each other and a third person who lacks experience. Such a team would provide an attractive training ground for an inexperienced resident or fellow. It provides the individual with the opportunity to gain experience, but his or her lack of experience would not significantly hurt the level of individual experience and experience working together on the team. The impact on procedure completion times could be minimized.

Understanding the performance of hospitals and the effectiveness of their training programs are important goals. Because this research advances our understanding of performance improvements in hospitals, we believe it makes a contribution. Other types of organizations are structured similarly to teaching hospitals in that individuals work on teams whose memberships change over time and are nested in larger organizations. For example, the organization of consulting firms has parallels to the organization of the teaching hospital we studied. Further research is needed to establish how well our results generalize to other contexts. This research should examine the conditions under which individual, team, and organizational experience become more (or less) important predictors of organizational learning outcomes. For example, individual experience may be more important in contexts where work is complex and jobs are designed to be high in skill requirements. Team experience may be especially important in contexts where task interdependence is high or when there is a great deal of uncertainty. These issues seem worthy of future research.

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References

Adler, P. S., K. B. Clark. 1991. Behind the learning curve: A sketch of the learning process. *Management Sci.* **37** 267–281.

Alchain, A. 1963. Reliability of progress curves in airframe production. *Econometrica* **31** 679–693.

Argote, L. 1999. *Organizational Learning: Creating, Retaining, and Transferring Knowledge*. Kluwer, Norwell, MA.

Argote, L., D. Epple. 1990. Learning curves in manufacturing. *Science* **247** 920–924.

Argote, L., S. L. Beckman, D. Epple. 1990. The persistence and transfer of learning in industrial settings. *Management Sci.* **36** 140–154.

Argote, L., B. McEvily, R. Reagans. 2003. Managing knowledge in organizations: An integrative framework and review of emerging themes. *Management Sci.* **49** 571–582.

Bailey, C. D. 1989. Forgetting and the learning curve: A laboratory study. *Management Sci.* **35** 340–352.

Baum, J. A. C., P. Ingram. 1998. Survival-enhancing learning in the Manhattan hotel industry, 1898–1980. *Management Sci.* **44** 996–1016.

Benkard, C. L. 2000. Learning and forgetting: The dynamics of aircraft production. *Amer. Econom. Rev.* **90** 1034–1054.

Bryk, A., S. Raudenbush. 1992. *Hierarchical Linear Models*. Sage, Newbury Park, CA.

Carley, K. 1992. Organizational learning and personnel turnover. *Organ. Sci.* **3** 20–46.

Darr, E., L. Argote, D. Epple. 1995. The acquisition, transfer and depreciation of knowledge in service organizations: Productivity in franchises. *Management Sci.* **41** 1750–1762.

Delaney, P. F., L. M. Reder, J. J. Staszewski, F. E. Ritter. 1998. The strategy-specific nature of improvement: The power law applies by strategy within task. *Psych. Sci.* **9** 1–7.

Dutton, J. M., A. Thomas. 1984. Treating progress functions as a managerial opportunity. *Acad. Management Rev.* **9** 235–247.

Edmondson, A., R. Bohmer, G. Pisano. 2001. Disrupted routines: Team learning and new technology implementation in hospitals. *Admin. Sci. Quart.* **46** 685–716.

Edmondson, A., A. Winslow, R. Bohmer, G. Pisano. 2003. Learning how and learning what: Effects of tacit and codified knowledge on performance improvement following technology adoption. *Decision Sci.* **34** 197–223.

Epple, D., L. Argote, R. Devadas. 1991. Organizational learning curves: A method for investigating intra-plant transfer of knowledge acquired through learning by doing. *Organ. Sci.* **2** 58–70.

Epple, D., L. Argote, K. Murphy. 1996. An empirical investigation of the microstructure of knowledge acquisition and transfer through learning by doing. *Oper. Res.* **44** 77–86.

Faraj, S., L. Sproull. 2000. Coordinating expertise in software development teams. *Management Sci.* **46** 1554–1568.

Graham, C. H., R. M. Gagne. 1940. The acquisition, extinction and spontaneous recovery of a conditioned operant response. *J. Experiment. Psych.* **26** 251–280.

Hatch, N., D. Mowery. 1998. Process innovation and learning by doing in semiconductor manufacturing. *Management Sci.* **44** 1461–1477.

Haunschild, P. R., B. N. Sullivan. 2002. Learning from complexity: Effects of prior accidents and incidents on airlines' learning. *Admin. Sci. Quart.* **47** 609–643.

Hofmann, D., M. Gavin. 1998. Centering decisions in hierarchical linear models: Implications for research in organizations. *J. Management* **24** 623–641.

Ingram, P. 2002. Interorganizational learning. J. A. C. Baum, ed. *The Blackwell Companion to Organizations*. Blackwell Business, Oxford, UK.

Ittner, C. D., V. Nagar, M. V. Rajan. 2001. An empirical examination of dynamic quality-based learning models. *Management Sci.* **47** 563–578.

Katz, J., E. Losina, J. Barrett, C. Phillips, N. Mahomed, R. Lew, E. Guadagnoli, W. Harris, R. Poss, J. Baron. 2001. Association between hospital and surgeon procedure volume and outcomes of total hip replacement in the United States Medicare population. *J. Bone Joint Surgery* **83** 1622–1629.

Kelsey, S. F., S. M. Mullin, K. M. Detre, H. Mitchell, M. J. Cowley, A. R. Gruentzig, K. M. Kent. 1984. Effect of investigator experience on percutaneous transluminal coronary angioplasty. *Amer. J. Cardiology* **53** 56C–64C.

Lapré, M. A., L. N. van Wassenhove. 2001. Creating and transferring knowledge for productivity improvement in factories. *Management Sci.* **47** 1311–1325.

Larson, J. R., C. Christensen, A. S. Abbott, T. M. Franz. 1996. Diagnosing groups: Charting the flow of information in medical decision-making teams. *J. Personality Social Psych.* **71** 315–330.

Lewis, K. 2003. Measuring transactive memory systems in the field: Scale development and validation. *J. Appl. Psych.* **88**(4) 587–604.

Liang, D. W., R. Moreland, L. Argote. 1995. Group versus individual training and group performance: The mediating role of transactive memory. *Personality Social Psych. Bull.* **21** 384–393.

Lieberman, M. B. 1987. The learning curve, diffusion, and competitive strategy. *Strategic Management J.* **8** 441–452.

Littell, R. C., G. A. Milliken, W. W. Stroup, R. D. Wolfinger. 1996. *SAS System for Mixed Models*. SAS Institute Inc., Cary, NC.

Moreland, R. L., L. Argote, R. Krishnan. 1996. Socially shared cognition at work: Transactive memory and group performance. J. L. Nye, A. M. Brower, eds. *What's So Social About Social Cognition? Social Cognition Research in Small Groups*. Sage, Thousand Oaks, CA, 57–84.

Newell, A., P. S. Rosenbloom. 1981. Mechanisms of skill acquisition and the law of practice. J. R. Anderson, ed. *Cognitive Skills and Their Acquisition*. Lawrence Erlbaum, Hillsdale, NJ, 1–55.

Nezlek, J., L. Zyzniewski. 1998. Using hierarchical linear modeling to analyze grouped data. *Group Dynam.* **2** 313–320.

Pisano, G. P. 1994. Knowledge, integration, and the locus of learning: An empirical analysis of process development. *Strategic Management J.* **15** 85–100.

Pisano, G. P., M. J. Bohmer, A. C. Edmondson. 2001. Organizational differences in rates of learning: Evidence from the adoption of minimally invasive cardiac surgery. *Management Sci.* **47** 752–768.

Rapping, L. 1965. Learning and World War II production functions. *Rev. Econom. Statist.* **47** 81–86.

Raudenbush, S., A. Bryk. 1986. A hierarchical model for studying school effects. *Soc. Ed.* **59** 1–17.

Shafer, S. M., D. A. Nembhard, M. V. Uzumeri. 2001. The effects of worker learning, forgetting, and heterogeneity on assembly line productivity. *Management Sci.* **47** 1639–1653.

Schulz, M. 2002. Organizational learning. J. A. C. Baum, ed. *The Blackwell Companion to Organizations*. Blackwell Business, Oxford, UK.

Terwiesch, C., R. E. Bohn. 2001. Learning and process improvement during production ramp-up. *Internat. J. Production Econom.* **70** 1–19.

Thorndike, E. L. 1898. Animal intelligence: An experimental study of the associative processes in animals. *Psych. Rev. Ser. Monogr. Supplements* **2** 1–109.

Thurstone, L. L. 1919. The learning curve equation. *Psych. Monogr.* **26** 1–51.

Uzzi, B. 1996. Sources and consequences of embeddedness for the economic performance of organizations. *Amer. Sociological Rev.* **61** 674–698.

Uzzi, B. 1997. Social structure and competition in interfirm networks: The paradox of embeddedness. *Admin. Sci. Quart.* **42** 35–67.

Uzzi, B., R. Lancaster. 2003. Relational embeddedness and learning: The case of bank loan managers and their clients. *Management Sci.* **49** 383–399.

Weber, R. A., C. Camerer. 2003. Cultural conflict and merger failure: An experimental approach. *Management Sci.* **49** 400–415.

Wegner, D. M. 1986. Transactive memory: A contemporary analysis of the group mind. B. Mullen, G. R. Goethals, eds. *Theories of Group Behavior*. Springer-Verlag, New York, 185–205.

Wegner, D. M. 1995. A computer network model of human transactive memory. *Social Cognition* **13** 319–339.

Wright, T. P. 1936. Factors affecting the costs of airplanes. *J. Aeronautical Sci.* **3** 122–128.

Zander, U., B. Kogut. 1995. Knowledge and the speed of the transfer and imitation of organizational capabilities: An empirical test. *Organ. Sci.* **6** 76–92.

Zhou, X. 2000. Economic transformation and income inequality in urban China: Evidence from panel data. *Amer. J. Sociology* **105** 1135–1174.