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## DESIGNING LEARNING: COGNITIVE SCIENCE PRINCIPLES FOR THE INNOVATIVE ORGANIZATION

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## First in a Paper Series: DESIGNING LEARNING: PRINCIPLES AND TECHNOLOGIES

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## **EXECUTIVE SUMMARY**

The central premise of this paper is that workplace learning can be *designed.* Innovative organizations can take principles from the cognitive science of learning and use them to organize their own company's training and development projects, designing technologies to support these projects. In this paper, we review some of the key principles of the cognitive science of learning as they can be observed in the way people think and act in different workplace activities. These key principles are summarized below, with some of the general ideas that we take up in the body of the paper outlined in their broadest form.

- Learning takes place within communities of practice. Even when we are learning how to do things for ourselves or on our own, like learning how to develop a presentation or spreadsheet, we rely on a variety of tools and others to do our work. Learning is embedded within everyday work activities: we learn by observing others who are more skilled than we are or by participating in more peripheral but nonetheless significant tasks as we are learning the different aspects of our work.
- Novices learn to become experts through practice in solving a variety of problems in a domain. Developing expertise in one's job requires extensive experience with the kinds of problems one is likely to face on the job. Experienced telephone sales operators, for example, have made thousands of calls to potential customers and are aware of a variety of kinds of problems they are likely to encounter on the job. They are more likely than novice sales operators to close sales because they are able to use fewer outside resources to answer customer questions. Moreover, they ask potential customers a targeted set of questions focused on the most relevant cost-related items, unlike novices, who follow scripts provided and treat all kinds of questions as equal in importance.

- *Becoming an expert means applying learning to new contexts.* Simulating situations commonly encountered on the job can provide learners with models for ways to solve new problems as they come up and better prepare learners than simply having them read in a book or training manual about problems they might face. On the other hand, learning that is too tightly coupled to a directly experienced situation is brittle. When confronted with a novel situation in which previously accumulated ways of approaching problems fail, we need something to fall back on. Because more general knowledge can be useful in coping with novelty, the most robust learning is likely to result from a combination of many experiences close to the target situation with some knowledge at a more general level.
- Prior knowledge mediates learning. What we know from our prior experience can get in the way of our ability to solve new problems. For example, many of our everyday concepts of motion and physics get in the way of our understanding of the scientific concept of force. On the job, schoolbased learning can interfere with the development of cognitively flexible solutions to complex problems, unless that learning can be reorganized to help solve the problems at hand.
- Learning is enhanced when thinking is made visible by collaboration and reflection among learners. Learners can improve their comprehension and mastery of a particular domain through active monitoring of their own learning. Active monitoring is best achieved when learners have the opportunity to share their ideas with others and reflect on their practice. For example, TAPPED IN, an on-line professional development forum, allows teachers to work together on projects remotely and to reflect collaboratively on their teaching through discussion and sharing resources with peers from around the country.

These principles of cognitive science point to an approach to learning that is quite different from the approach of many workplace training departments. Learning, according to cognitive science, should no longer be viewed as a process of simply transmitting information from a teacher to a learner or from an expert to a novice. Rather, learning should be viewed as an active, constructive process, involving collaboration and reflection among people who learn through the course of their everyday activity.

New technologies can support learning activities designed according to these cognitive science principles. The capabilities of technology to support communication and collaboration, the presentation of interactive animated and graphical conceptual tools, and simulation of problem solving match what we know about how people learn, both in and beyond classrooms. Such technologies, if they are designed well and are well understood by developers and users, have the potential to revolutionize corporate learning and innovation. representations with respect to the use of the information contained in SRI's report, nor does SRI endorse, expressly or by implication, Lotus' use of any SRI provided information.

#### INTRODUCTION

Nearly one-quarter of new jobs created today in the United States are technical or professional jobs.<sup>1</sup> Nearly all work, moreover, is becoming more and more technical; that is, it is becoming more complex, analytic, and even abstract.<sup>2</sup> It requires workers who are able to blend craft and science, drawing on both structured, abstract knowledge of their specialization and tacit knowledge of how people, processes, and technologies must function together to accomplish their work. As technology becomes increasingly important in automating work processes, the result has not been to deskill workers so much as to require them to be good at handling the difficult exceptions and problems that computers can't handle. For example, we now speak to the live customer service representative on the phone after the computer's preselected solutions to common problems have been exhausted.

The challenge of training people for this kind of work has become a pressing problem for companies as more and more of their workers need to learn these skills to do their jobs. Every company's bottom line requires competent work, and errors (whether by novices or experienced workers) are often costly, if not catastrophic. It's not acceptable to have medical technicians, for example, perform erroneous blood tests on patients as novices on the job. And yet many companies' training programs show mixed results, and many are believed by management to be costly and ineffective.<sup>3</sup>

A smaller number of companies, however, have developed strategies that support workplace learning in ways that prepare workers for the kinds of work that are more and more ubiquitous in U.S. companies. Understanding why some organizations foster innovation and excellence among employees more than

<sup>&</sup>lt;sup>1</sup> Barley, S. R., & Orr, J. E. (1997). *Between craft and science: Technical work in U.S. settings.* Ithaca, NY: Cornell University Press.

<sup>&</sup>lt;sup>2</sup> Barley & Orr. (1997).

<sup>&</sup>lt;sup>3</sup> Schanck, R. (1997). *Virtual learning: A revolutionary approach to building a highly skilled workforce.* New York: McGraw Hill.

others requires that we understand something about the science of human learning. In this paper, we outline some of the key principles within cognitive science—the study of how human beings learn—and show how they shape workplace learning. Throughout, we provide illustrations of workplace learning that is mediated by the use of technology, an increasingly ubiquitous tool for workers at all levels and across all business sectors. Finally, we consider some of the implications of this research for *designing workplace learning*. Innovative organizations can take principles from the cognitive science of learning and use them to organize their own company's training and development projects, designing technologies to support these projects.

Before we introduce these principles, though, let us take up an example of a company that designed a set of fairly simple tools to help its repair technicians do their jobs more effectively. The project we describe is unusual, in that it relies not just on formal training to achieve its ends: rather, it builds on an existing culture of learning among workers. We'll return to this company's project again at the end of our paper to review the science behind the project's success. At stake here is a new model of learning that integrates the insights of cognitive science, one that has important implications for innovative companies.

## WHAT DIFFERENCE DOES THE LEARNING ENVIRONMENT MAKE? The Denver Project: Learning in a Large Organization

A common problem for businesses is to help workers learn how to improve their practice. The researcher Julian Orr describes a project aimed at helping repair technicians become more competent practitioners.<sup>4</sup> The "Denver Project," as it was called, was a unique experiment in that it involved representatives of corporate research and corporate development groups

<sup>&</sup>lt;sup>4</sup> Orr, J. E. (1993). Ethnography and organizational learning: In pursuit of learning at work. In S. Bagnara, C. Zucchermaglio, & S. Stucky (Eds.), *Organizational learning and technological change.* New York and Berlin: Springer Verlag.

working alongside technicians to develop technologies that would facilitate learning.

The Denver Project took place in a large corporation that manufactures photocopiers and other office equipment. The corporation's previous training efforts for technicians by the corporation had focused on providing what is known as "directive documentation."<sup>5</sup> Directive documentation (like a training manual) is often used in corporations to provide workers with information on processes or problem-solving strategies they might encounter. In this company, it aimed at providing technicians with a decision tree to determine which repair procedure to follow. The kinds of problems identified in the decision tree are defined by the designers of the documentation, who must rely on data about commonly encountered problems to generate their list of procedures. Technicians learn how to solve these most commonly encountered problems early in their jobs and share information with each other about their solutions. What takes technicians more time and makes customers anxious are the uncommon problems, and designers have had little success in identifying an exhaustive list of problems. Moreover, the decision trees focus on problems with machines, whereas many of the problems technicians must deal with pertain to relationships with *customers* and between customers and their machines.

Orr found that photocopier repair technicians had their own informal ways of learning to become competent technicians. Orr had conducted a study of their work two years earlier and had described some interesting aspects of technicians' work culture.<sup>6</sup> They formed an occupational community,<sup>7</sup> which is a community that has little internal hierarchical work structure and whose

 <sup>&</sup>lt;sup>5</sup> Orr, J. E. (1991). Sharing knowledge, celebrating identity: War stories and community memory among service technicians. In D. S. Middleton & D. Edwards (Eds.), *Collective remembering: Memory in society* (pp. 169-189). Newbury Park, CA: Sage.
<sup>6</sup> Ibid.

members have few formal opportunities for advancement in the company. Information sharing was part of their work culture, and story telling was an important practice within that culture. Repair technicians told "war stories" about particular machine repairs, client relationships, and their own mistakes as a means of developing and demonstrating their competence as technicians and as a means of collective remembering. This collective remembering preserved knowledge of different repair situations, which could be applied to new, unanticipated problems. Technicians used the old knowledge—told through stories shared and reconstructed by technicians—when they recognized familiar patterns emerging in a new situation.

The Denver Project, unlike previous efforts in training, was designed to support existing learning practices of repair technicians. The technicians were given portable radios for communicating with other technicians. Interestingly, the group of researchers, systems development experts, and technicians decided to keep the radio technology out of the hands of the technicians' managers in order to preserve the free flow of information from technician to technician that was part of their culture. With the new technologies, the stories that previously had to be shared face-to-face could now be shared on the go, whether between service calls or after work on the way home. In addition, they could consult with other technicians and draw on their expertise in dealing with a particular problem, whether it was a difficult machine or an angry customer. According to Orr, the technicians were able to resolve unusual customer problems more rapidly and enjoyed providing problem-focused and moral support to their peers through the radios.<sup>8</sup>

#### FORMAL AND INFORMAL LEARNING ENVIRONMENTS

<sup>&</sup>lt;sup>7</sup> Van Maanen, J., & Barley, S. R. (1984). Occupational communities: Culture and control in organizations. In B. M. Staw & L. L. Cummings (Eds.), *Research in organizational behavior*, (Vol. 6). Greenwich, CT: JAI Press.

<sup>&</sup>lt;sup>8</sup> Orr, J. E. (1993).

It is no accident that the Denver Project succeeded where previous training efforts had fallen short. Formal training programs, directive documentation, and other tools employed by companies often contain elements of what has been called the "grammar of schooling."<sup>9</sup> The grammar of schooling refers to the kinds of things we usually think about when we think about school or even formal training sessions in the workplace. There's an expert standing in front of the room, imparting knowledge to students who listen quietly. There's a curriculum or binder that the trainer or teacher must cover in the time allotted. At the end, students are tested on what they know and sent out into the world to apply their learning to the next level of schooling or to their new work context by using the knowledge provided to them in the classroom to make decisions and solve problems they encounter.

Such training models apply to work settings that are stable and where the problems that workers encounter can be easily and exhaustively identified. At the same time, such formal learning environments often fail in the ways that the directive documentation failed the technicians. There may be a disconnection between the problems trainers anticipate and problems workers actually encounter. Also, workers' own learning practices may be at odds with formal training programs. Finally, workers may develop a belief that the corporation's own training programs only weakly support the demands of their job.

The technicians' own learning practices on the job are an example of an *informal learning environment*. Informal learning environments, which include work settings, community or voluntary associations, museums, and recreational centers, may not regard learning or the delivery of content as their primary objective or focus.<sup>10</sup> Rather, the goal may be the performance of some work or

<sup>&</sup>lt;sup>9</sup> Tyack, D., & Cuban, L. (1995). *Tinkering toward utopia: A century of public school reform.* Cambridge, MA: Harvard University Press.

<sup>&</sup>lt;sup>10</sup> Schauble, L., Beane, D. B., Coates, G. D., Martin, L. M. W., & Sterling, P. V. (1996). Outside the classroom walls: Learning in informal environments. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for learning.* Mahwah, NJ: Lawrence Erlbaum.

simply getting together with friends. At the same time, there is a design to activities within informal learning environments, and this design is often focused on the promotion of social interaction and the development of relationships among participants.<sup>11</sup> Learning in informal environments, moreover, is typically embedded within the activities of everyday life, such that the line between "learning" and "life" is blurred.<sup>12</sup> The embeddedness of such learning means that informal learning environments are able to build on routine problems encountered in daily activities.<sup>13</sup> As a result, learning is typically more "fun" in informal learning environments, because the interests and talents of participants are resources for learning within these contexts.<sup>14</sup>

Understanding what makes informal learning environments so powerful and robust requires a deeper investigation of what we know about how people learn. Surprisingly, many informal learning environments are more likely to facilitate learning than formal learning environments built around the traditional grammar of schooling. To understand why, we now present some of the basic findings of researchers in the field of cognitive science, which has drawn on insights from fields as far ranging as anthropology and neuroscience to discover how people learn.

### **RESULTS FROM THE COGNITIVE SCIENCE OF LEARNING**

For several decades now, the field of cognitive science has increased our understanding of how people learn through research by psychologists, neuroscientists, sociologists, anthropologists, and others studying human mental functioning in context. In this section, we discuss some key results from this

<sup>&</sup>lt;sup>11</sup> Schauble *et al.* (1996). See also Heath, S. B., & McLaughlin, M. W. (Eds.), (1993). *Identity and inner city youth: Beyond ethnicity and gender*. New York: Teachers College Press. <sup>12</sup> Schauble *et al.* (1996).

<sup>&</sup>lt;sup>13</sup> Lave, J., Murtaugh, M., & de la Rocha, O. (1984). The dialectic of arithmetic in grocery shopping. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context* (pp. 67-94). Cambridge, MA: Harvard University Press.

<sup>&</sup>lt;sup>14</sup> Schauble *et al.* (1996).

emerging science of learning, with particular reference to how different learning environments might be designed to maximize learning. We have expressed these key results in the form of several statements about the nature of learning or about the conditions under which learning is maximized, which appear in Table 1.

## Table 1.Key Findings from the Cognitive Science of Learning

1. Learning takes place within communities of practice. 2. Novices learn to become experts through practice in solving a

variety of problems in a domain.

3. Becoming an expert means applying learning to new contexts.

4. Prior knowledge mediates learning.

5. Learning is enhanced when thinking is made visible by collaboration and reflection among learners.

We now consider each of these results in greater detail, with examples from the worlds of work, school, and everyday life to illustrate how these results can be observed in a variety of learning environments.

## Learning Takes Place within Communities of Practice

The term *community* has become more widely used in recent years. We now often refer to such entities as the business community, the law enforcement community, or the school community. Often, *community* applies to a wide range of ways that people organize themselves. It may refer to people who have formed a temporary association based on a hobby or to a group of workers within a business sector who have been organized for decades. It is important, then, to specify what is meant by *community* if we are to understand what it means to claim that learning takes place within communities.

Cognitive psychologists within the fields of cultural psychology,<sup>15</sup> anthropology,<sup>16</sup> and sociology<sup>17</sup> have used the term *community of practice* to

<sup>&</sup>lt;sup>15</sup> Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Harvard University Press.

<sup>&</sup>lt;sup>16</sup> Ortner, S. B. (1984). Theory in anthropology since the Sixties. *Comparative Studies in Society and History, 26.* 

Rabinow, P. (1996). *Essays on the anthropology of reason.* Princeton, NJ: Princeton University Press.

<sup>&</sup>lt;sup>17</sup> Bordieu, P. (1977). *Outline of a theory of practice.* Cambridge: Cambridge University Press.

describe contexts of learning and development. This term emphasizes that communities are typically organized around things that members *do* or *make*.<sup>18</sup> If we want to understand how people become skillful participants in these activities, we'll need to have a better understanding of the built-in opportunities for learning that are embedded in the ways people cooperatively organize their work. Examining how workers learn to use technologies is an excellent context for observing learning in communities of practice, because so much of this kind of learning is embedded in ongoing work practice and in achieving goals embedded in individual and collective work practice.<sup>19</sup>

Bonni Nardi and James Miller have taken up this problem in their study of how people work together to develop spreadsheets.<sup>20</sup> Most of us probably think of making a spreadsheet as a solo activity: the software is typically designed as a "single-user" program that sits on our individual desktops. In most organizations where spreadsheets are used, however, designing spreadsheets is a collaborative activity that involves a community of practice of "spreadsheet designer-users." Within this community, there are three groups of people with different levels of skill in designing spreadsheets: programmers, who have a good understanding of computing and programming languages; local developers, who have extensive experience with particular applications and are likely to read manuals and know how to use advanced features of applications; and nonprogrammers, whose primary task is developing spreadsheets to analyze data they use in their work and who have little or no formal training in programming.

Nonprogrammers are not just "end-users" who use spreadsheets to complete goals already defined by programmers or developers. They often are

<sup>&</sup>lt;sup>18</sup> Lemke, J. L. (1995). *Textual politics: Discourse and social dynamics*. London: Taylor & Francis.

<sup>&</sup>lt;sup>19</sup> Allen, C., Linde, C., Pea, R., de Vet, J., and de Vogel, R. (1991). *Picasso Project: Final report.* Menlo Park, CA: Institute for Research on Learning.

<sup>&</sup>lt;sup>20</sup> Nardi, B., & Miller, J. R. (1991). Twinkling lights and nested loops: Distributed problem solving and spreadsheet development. *International Journal of Man-Machine Studies, 34*, 161-184.

quite skilled in using some of the basic features of spreadsheets to create their own designs. They are able to add values to cells or delete them, devise simple formulas, or even make layout changes to their spreadsheet's fonts, colors, and basic organization. Still, to accomplish the particular goals of their project, nonprogrammers may need to rely on expertise within their organization to develop their spreadsheets.

The work of developing spreadsheets is collaborative at several points during the process. As nonprogrammers get "stuck," they may ask the more experienced users (programmers and local developers) to contribute code to the spreadsheets, whether by developing complex charts and graphs or by helping out with developing more complex formulas. Once spreadsheets are developed, the work of "debugging" or checking the spreadsheet for errors is done by someone other than the primary developer. Other nonprogrammers or local developers may cross-check on-line versions or hard copies of the spreadsheets to try to eliminate errors that could have serious consequences. Cooperation is key here, in that errors often become invisible to the original developers, and errors are inevitable consequences of complex work activities like spreadsheet development.<sup>21</sup>

Working together in this way inevitably involves teaching and learning as well. The fact that spreadsheets are designed so that people can develop them with mastery of either "fundamental" (e.g., entering values into a cell, defining basic formulas) or "advanced" (e.g., creating and modifying graphs for presentations) features means that expertise can develop on at least two different levels. In spreadsheet development, more experienced users (programmers and local developers) teach less experienced users about some of the advanced features of their spreadsheets. They do so informally on an as-needed basis to accomplish the particular goals of the primary developer. Sometimes,

<sup>&</sup>lt;sup>21</sup> Norman, D. A. (1988). *The design of everyday things*. New York: Doubleday.

nonprogrammers see an advanced feature in another user's spreadsheet and ask a local developer how to build that feature into their own spreadsheet.

Nonprogrammers, local developers, and programmers, then, constitute an interdependent community of practice in which learning is taking place all the time. Nardi and Miller's study of spreadsheet developers illustrates a key finding within the cognitive science of learning: learning is not separate from ongoing activity but rather is a part of it.<sup>22</sup> Learning to become a member of a community of practice, therefore, requires not just observing from the outside but participating in the doings and makings of the community from within.<sup>23</sup>

Nardi and Miller's study also points to an important insight about designing technologies that support this kind of learning. The fact that spreadsheets' functionality can be described as having two layers, fundamental and advanced, allows groups of people to distribute labor across tasks according to their level of expertise. Developing a spreadsheet does not depend on one person's having all the relevant knowledge for building it—the data to be used, the design, and the programming required. Instead, a community of practice can distribute these tasks across people for greater efficiency.

# Novices Learn to Become Experts through Practice in Solving a Variety of Problems in a Domain

Another thread of research in cognitive science has sought clues about the nature of learning by examining the differences between experts and novices. The idea is to understand what learning must accomplish by identifying qualitative changes that occur as expertise develops over many years. Expertnovice research thus provides a valuable counterpoint to more common learning

 <sup>&</sup>lt;sup>22</sup> Lave, J. (1984). *Cognition in practice.* Cambridge: Cambridge University Press.
<sup>23</sup> Lave, J. (1991).

Rogoff, B., Baker-Sennett, J., Lacasa, P., & Goldsmith, D. (1995). Development through participation in sociocultural activity. In J. J. Goodnow, P. J. Miller, & F. Kessel (Eds.), *Cultural practices as contexts for development* (pp. 45-65). San Francisco: Jossey-Bass.

studies, which examine short-term learning (over minutes or days) but not longterm learning (over years).

A classic set of studies by Simon examines expert-novice differences in chess. What makes a chess master different from a casual player? A key difference to emerge from the research is that experts recognize a huge repertoire of patterns—on the order of 50,000 distinct variations—and upon recognition of a particular pattern, they know what to do next. Interestingly, for example, the performance of a chess master does not degrade much when playing 10 games simultaneously against different challengers with only a minute or two to examine each board. Most of what chess masters do is to recognize patterns and appropriate next moves. In contrast, casual players recognize fewer patterns and must do much more reasoning from the basic rules of the game.

In another classic study,<sup>24</sup> chess masters were shown a mix of normal and impossible board positions. After a glance at the board position, the masters were able to recall and reproduce the configuration almost exactly, but only if the board was in a configuration that could be achieved during game play; experts fared no better than novices at remembering boards in which pieces were placed randomly. Both this recall study and the study of simultaneous play show that experts in chess rely on memory of patterns, rather than simply having better general reasoning or memorization abilities.

The ability of experts to recognize relevant patterns can have some important consequences for business expertise, where "expertness" might mean the difference between making or not making a big sale. Laufer and Glick's<sup>25</sup> study of telephone sales staff within several industrial precision-parts distributor companies is a case in point. Selling over the phone in these companies was a complex matter, involving obtaining orders from buyers, checking inventory,

<sup>&</sup>lt;sup>24</sup> Simon, H. A., & Chase, W. G. (1973). Skill in chess. *American Scientist, 61*, 394-403.

buying products from other sources if needed, and quoting prices to potential customers. Each order included five special precision parts, and to meet industry standards the telephone operator had to ask 65 different questions to specify all five items. Not surprisingly, novice sales staff had a hard time getting through so many questions to customers, and it took them a long time to do all the steps required to fill an order. Experts were much better at getting out more questions and were far more efficient in sales.

But experts weren't just better at asking questions: they were more knowledgeable about the significant dimensions of pricing than novices. Expert sales staff still didn't ask the required 65 questions; instead, they relied on asking more "trigger" questions—that is, questions that focused on asking potential customers about the most price-sensitive items in their order—and ignoring much of the rest. Where novice sales staff thought they needed to know everything and followed the list of questions as if all questions were of equal importance, expert sales staff recognized the greater significance of some questions to securing a sale. They could "guesstimate" the price of the order on the spot, using information learned about the most price-sensitive aspects of the customer's order and thus were more likely to close a sale in a shorter time than the novices.

The major implication of expert-novice research for the design of learning environments is that learners need to encounter a wide variety of cases. Moreover, it is desirable that learners associate those cases with successful actions. Since novices will need to master a potentially large number of patterns, long periods of supervised practice are essential. This principle is already reflected in the structure of many professional apprenticeships, such as residency for doctors, junior associate positions for lawyers, or postdoctoral positions for

<sup>&</sup>lt;sup>25</sup> Laufer, E. A., & Glick, J. (1996). Expert and novice differences in cognition and activity: A practical work activity. In Y. Engestrom & D. Middleton (Eds.), *Cognition and communication at work* (pp. 177-198). Cambridge: Cambridge University Press.

scientists. Medical residencies, for example, deliberately expose trainees to a wide sample of the most difficult medical cases, with supervision from an attending physician who guides the resident to successful action.

Learning technologies can help with this process by expanding practice opportunities. For example, chess players could use a computerized partner to play many more chess games than they might be able to play against a real player. Moreover, the computerized player might be programmed to play in a wider variety of styles than any single human player might exhibit. Likewise, simulations might make available cases that are rarely encountered in medicine. Technologies can also help by highlighting the deep features of situations, helping novices to see beyond superficial patterns. For example, in working through a set of simulations of potential problems in flight, novice pilots making similar mistakes on a set of problems that have similar kinds of solutions might be given feedback by the simulator to notice the similarity across the problem situations.

#### Becoming an Expert Means Applying Learning to Novel Situations

We are all familiar with the caricature of the absent-minded professor: the fellow in the tattered suit who readily solves complex Newtonian equations to predict the exact location of a moving body but can't manage to get his car out of the driveway without hitting the telephone pole. This poor fellow is a case study in the flip side of learning: the problem of transfer. *Transfer* typically refers to the process of taking something learned in one context and applying it in another. As the professor shows, the fact that you can solve a problem correctly when framed as a blackboard idealization doesn't mean you can solve the "same" problem when confronted with it in the course of action. One might also ask: what is the point of learning, if not to be able to transfer knowledge to a new situation?

In some cases, it is fairly obvious that relying on transfer can be hazardous to your health. No one, for example, would board an airplane if the pilot had learned the skills of flying only from a textbook. To the contrary, we insist that the pilot have flown a large number of flights before. Even more to the point, pilots test their mettle in simulators that can present them with unusually difficult situations in a realistic context. Intuitively, we expect that lessons learned from prior experience and from simulations will transfer, whereas we doubt that lessons learned from a textbook or lecture will suffice to pull us out of a nosedive.

In other cases, failure to transfer seems more surprising. A physics professor<sup>26</sup> once recounted the story of the doctoral candidate who failed miserably at his qualifying examination. All through his graduate career, the candidate had been asked to solve complicated formal problems. But at the oral exam, the questioners realized that they would soon be supervising the candidate's laboratory research and decided to ask more practical questions. When the candidate resorted to calculation to determine the answers, the questioners grew frustrated because they wanted an intuitive response that demonstrated competence in the lab. The problem here is unanticipated failure to transfer: the physics professors had trained the candidate in formal problem solving but wanted to assess the candidate (who would be their future colleague) about informal laboratory know-how.

Cognitive scientists have been struggling with the issue of transfer for nearly a century: "Can we predict in which situations learners will correctly apply their knowledge and in which they will not?" Thorndike<sup>27</sup> originally proposed the theory of "identical elements," which states roughly that learning will transfer if the elements of the new situation are identical to those of the old. Ever since, researchers have struggled with the question of just what makes an identical element. On one hand, no two situations are ever really exactly the

<sup>&</sup>lt;sup>26</sup> Reif, F. (1991). Personal communication.

<sup>&</sup>lt;sup>27</sup> Thorndike, E. L., & Woodsworth, R. S. (1901). The influence of improvement in one mental function upon the efficacy of other functions. *Psychological Review*, *8*, 247-261.

same. Inevitably, people must *interpret* a particular situation as "the same" or "different": identical elements are not givens in a particular situation.<sup>28</sup> On the other hand, people obviously manage to cope with many new situations unproblematically. The debate is still unresolved, with some researchers claiming that learning is completely situation dependent and others holding out for the possibility of general instruction that applies to many specific situations.<sup>29</sup>

Nonetheless, research can point to some practical advice. Transfer is clearly more likely if the learning situation provides the same form of experience and evokes the same kinds of responses. Hence, a simulation of flying a plane is better than a textbook explanation of how to fly a plane. However, learning that is too tightly coupled to a directly experienced situation is brittle. When confronted with a novel situation in which previously accumulated ways of approaching problems fail, we need something to fall back on. More general knowledge can be useful in coping with novelty. For example, the doctor who encounters a rare tropical disease he has only read about in books is still better off than the less-well-read doctor who has only experience with other kinds of disease. The most robust learning, therefore, is likely to result from a combination of many experiences close to the target situation with some knowledge at a more general level. For example, the car mechanics featured on the radio show "Car Talk" routinely solve problems that have stumped local garages. In doing so, they draw on both a wealth of practical experience in fixing cars and broad knowledge of how cars work.

The observation that simulation can support learning better than more abstract textbook presentations leads to a direct role for technology: creating

<sup>&</sup>lt;sup>28</sup> Pea, R. D. (1987). Socializing the knowledge transfer problem. *International Journal of Educational Research*, *11*, 639-663.

<sup>&</sup>lt;sup>29</sup> Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher*, *25*, 5-11.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1997). Situative versus cognitive perspectives: Form versus substance. *Educational Researcher*, *26*, 18-21.

Greeno, J. G. (1997). On claims that answer the wrong question. Educational Researcher, 26, 5-17.

learning experiences that bear a close similarity to the contexts in which the results of learning will be applied. Technological simulations and representations are powerful tools that can be designed to directly address the knowledge transfer problem.<sup>30</sup> However, it may be less obvious at first how technology can support the corollary of recognizing the applicability of more general concepts to specific situations.

## **Prior Knowledge Mediates Learning**

Many school children know that serving a drink in a foam cup will keep it hot. Why, then, does a simple laboratory experiment show that a foam wrapper can also keep things cool?

Experience tells us that organized social behavior requires a leader. How, then, do fish school and birds flock even though there is no leader who tells the others what to do?

Everyday interactions with objects lead us to the generalization that they will move if a force is applied. How, then, can it be that Newton was correct in saying that a table applies an upward force on a book that rests without motion on top of it?

In each case above, learning is made difficult by prior knowledge based on a commonsense concept that conflicts with scientific understanding of the situation. Scientists view foam as an *insulator* rather than a heat maintainer and thus explain that it prevents heat exchange between a liquid and either a hotter or cooler external environment. Scientists view flocking and schooling as selforganizing behaviors that arise from following simple rules and thus explain flocking or schooling as emerging when each animal reacts to its neighbor animal

<sup>&</sup>lt;sup>30</sup> Pea, R. D. (1987).

in a consistent way. Scientists see gravity as acting on every object near the Earth and thus postulate the need for some force from the table to counteract the downward force on the book.

Such conflicts in point of view have been shown to interfere with learning. In these cases, our everyday experience gets in the way of our understanding of scientific concepts. Sometimes, school learning itself is the culprit. For example, expert dairy loaders' ability to fill out complex orders involving removing or adding units of milk or juice to cases to load on trucks is far better than the skill of clerks or students, who tend to apply school-based mathematics strategies to such problems.<sup>31</sup> The expert dairy loaders are far better at loading trucks so that they exert the least physical effort. Moreover, they know when to use a mathematical operation to determine how to organize and reorganize cases to fill different orders. Clerks and students, on the other hand, often use mathematics when they don't have to, and they make the mathematics more difficult than they have to. Their school knowledge, which mediates their whole approach to the task, gets in the way of their performance of the task.

Learning to become an expert dairy loader doesn't involve eliminating all school-based knowledge of mathematics, however. It turns out that dairy loaders use a combination of mathematics and *seeing* the patterns of how milk is organized in the cases. They hardly ever have to count the number of bottles of milk left in a half-empty case, whereas clerks and students can be seen pointing to the bottles as they count the ones remaining. Through experience with loading trucks, dairy loaders develop skill in combining locally developed, "on-the-job" knowledge with prior knowledge in such a way that their prior knowledge is reorganized to help them do their job with the least amount of physical effort. The dairy loaders' prior knowledge is reorganized through the transformation of

<sup>&</sup>lt;sup>31</sup> Scribner, S. (1984). Studying working intelligence. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context* (pp. 9-40). Cambridge: Harvard University Press.

their participation in the activity of dairy loading from "novice" to "expert" performance.

Technology can often help in this process by providing representations, models, and analogies that support learners' reorganization of their prior knowledge to become more useful to them in their everyday work. Designing such technologies is not easy, because the models provided need to reflect more than just the expert point of view. Rather, successful representations are designed to be a bridge between prior and target knowledge and practice. Exposure to such representations allows the novice to see the expert approach to effective thinking on the job as a useful addition to her own repertoire and allows the expert to see the novice's view as a prior stage in the development of work practice that might be refined toward more competent practice.

## Learning Is Enhanced When Thinking Is Made Visible by Collaboration and Reflection among Learners

The work cited in previous sections rests on a central assumption about the basis for learning, namely, that learning can trace its origins to social activity.<sup>32</sup> According to the Russian psychologist Vygotsky, social settings in which experts or more capable peers are present provide strategic support to learners so that they can perform at higher levels than they would be able to achieve unassisted by others.<sup>33</sup> It is through learners' interactions with others in concrete settings, moreover, that they learn to become competent members of communities of practice. Through practicing with others in using the ways of

<sup>&</sup>lt;sup>32</sup> Wertsch, J. V. (1991). *Voices of the mind: A sociocultural approach to mediated action*. Cambridge: Harvard University Press.

<sup>&</sup>lt;sup>33</sup> Vygotsky calls this phenomenon the *zone of proximal development*, defined as the difference between a child's actual developmental level achieved through independent problem solving and the potential level of performance determined under the conditions of guided participation (see Wertsch, 1991, p. 28).

speaking, thinking, and valuing of particular communities of practice, learners come to enhance their identities within those communities.<sup>34</sup>

In traditional formal learning environments such as classrooms, there is often little opportunity for learners to interact with each other or with the material they are expected to master. Moreover, learner feedback in traditional settings relies on teacher evaluations of pencil-and-paper assignments. These evaluations frequently take some days or even weeks to provide to students, resulting in a much longer feedback cycle than research suggests is optimal for learning.<sup>35</sup> Many new collaborative technologies, however, enable learners to collaborate to share and test ideas and use their peers' and teachers' feedback immediately to reflect on what they've learned and revise misconceptions.

The CSILE (Computer-Supported Intentional Learning Environments) program is an example of just such a technology-supported project being implemented in K-12 education.<sup>36</sup> The goal of CSILE is to support structured, collaborative knowledge building within a particular domain. Its architecture permits remote collaboration, so that students and teachers do not have to be colocated in time or place to participate. CSILE is a networked community knowledge database into which students contribute their ideas in the form of questions, textual statements, or visual annotations or diagrams. CSILE has built-in strategic supports—"scaffolds,"<sup>37</sup> as they are sometimes called—that guide learners much in the way expert human beings might guide novices through participation in an activity in which they are becoming proficient. These supports help structure the discussion and help students learn to reason with evidence to support theories they are developing about the phenomena they are studying.

<sup>&</sup>lt;sup>34</sup> Lave & Wenger. (1991).

<sup>&</sup>lt;sup>35</sup> Anderson, J. R. (1996). *The architecture of cognition*. Mahwah, NJ: Lawrence Erlbaum Associates.

<sup>&</sup>lt;sup>36</sup> Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences, 3*, 265-283.

<sup>&</sup>lt;sup>37</sup> Bruner, J. S., Wood, D., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, *17*, 89-100.

CSILE also supports student reflection about what they are learning, another important aspect of learning. Monitoring one's own learning actively by regulating one's thinking through planning and checking understanding is central to the learning process.<sup>38</sup> Collaborative processes, moreover, support this kind of monitoring by providing contexts for learners to test their ideas, develop arguments using evidence to support their ideas, and have their ideas be subjected to feedback and critique by others. The CSILE environment, it turns out, supports just this kind of reflection. Students using CSILE were more likely than students working in face-to-face conditions to monitor and regulate their learning and engage in more problem-centered discourse about the topic under investigation.<sup>39</sup>

Providing opportunities for adults to collaborate and reflect on their ideas is critical for their learning, as well. Technologies here can play a powerful role in supplementing costly and difficult-to-arrange face-to-face meetings. For example, a learning environment called TAPPED IN<sup>40</sup> enables teachers from around the country to meet and learn together in a virtual conference center via the Internet. TAPPED IN supports teacher collaboration and resource sharing. It also promotes reflection on teaching practice, as evidenced by teachers' use of conference and chat rooms within the environment for problem solving, planning, and mentoring.

## From Information Transmission to Social Construction of Knowledge: A New Model of Learning

<sup>&</sup>lt;sup>38</sup> Brown, A. L. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. E. Wienert & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 65-116). Hillsdale, NJ: Lawrence Erlbaum Associates.

<sup>&</sup>lt;sup>39</sup> Cohen, A. L., & Scardamalia, M. (1998). Discourse about ideas: Monitoring and regulation in face-to-face and computer-mediated environments. *Interactive Learning Environments, 6*, 93-113.

<sup>&</sup>lt;sup>40</sup> Schlager, M. S., & Schank, P. K. (1997). TAPPED IN: A new on-line teacher community concept for the next generation of Internet technology. In *Proceedings of CSCL '97: The Second International Conference on Computer Support for Collaborative Learning*, pp. 230-241.

If we now revisit the Denver Project, we can see many reasons why technicians may have been more successful in learning from each other via mobile radios than they had been in learning from directive documentation and standard classroom training (see Table 2).

## Table 2.

Learning takes place within communities of practice.	The Denver Project built on the strengths of the technicians' informal community of practice.
Novices learn to become experts through practice in solving a variety of problems in a domain.	Novice technicians were able to draw on the pattern recognition capabilities of the more expert technicians, thus allowing the community as a whole to develop collective memory of a larger variety of problematic cases.
Becoming an expert means applying learning to new contexts.	The Denver Project narrowed the transfer gap by providing learning opportunities exactly within the cases where the knowledge would be applied.
Prior knowledge mediates learning.	Fellow technicians were probably more adept than documentation authors at framing problem solutions in terms that drew on anchoring concepts in technicians' knowledge.
Learning is enhanced when thinking is made visible by collaboration and reflection among learners.	The mobile radios supported collaboration and reflection among technicians focused on challenging repair problems.

## **Cognitive Science Principles Embedded in the Denver Project**

Cognitive science thus provides scientific backing for the success of the Denver Project in supporting technicians' learning. In so doing, cognitive science backs a quite revolutionary view of learning, at least relative to the standard practices in traditional lecture-, text-, and classroom-based environments. In the remainder of this paper, we step back from the details of specific settings and research findings to suggest a new model of learning that is emerging from research.

As it stands, there are many different theories in cognitive science, based on a variety of core metaphors, research focuses, and methodological approaches. It would be too strong to say that cognitive science is converging on a new theory of learning. Nonetheless, there is convergence on the basic attributes of a model of successful learning. This emerging model, which might be labeled "social construction of situated knowledge," stands in stark contrast to older, transmission-oriented views of teaching and learning. The word *social* refers to the importance of collaborative, community-based, conversational work in building understanding. It underscores that learning is at its heart a social process:

- The goal of participating in a community of practice often drives learning.
- Conversation with others often is necessary to clarify important ideas and reach mutual understanding.
- Collaboration provides an important forum for reflection on progress and difficulties in learning.

The word *construction* refers to the importance of active, engaged building of new knowledge from prior knowledge and new experience. Becoming an expert requires building a large repertoire of patterns that can be recognized and acted on. There is no known mechanism for short-cutting direct experience of the situations of practice in order to build up these patterns. Moreover, learning is constructive because learners grow new knowledge from anchors in their current ways of thinking; some learning can be assimilated to existing knowledge, but more difficult learning requires modifying existing knowledge to accommodate a more sophisticated perspective.

Finally, we say learning is *situated* because of the uncertainties surrounding transfer. The process of learning tends to incorporate aspects of the learning context in what is learned, and learners may have difficulty using that knowledge in varying situations. Both physical and social aspects of situatedness are important: learning is distributed across both other people and physical tools.

A situated, social, constructivist view differs from a more conventional transmission theory of learning in both theory and implications. From the point of view of theory, modern learning theory emphasizes *contextualization*, whereas the older transmission view tries to communicate disembodied ideas via lecture or text. Further, transmission theories often assumed that knowledge could be passed from teacher to learner without significant distortion or transformation. In contrast, newer theories recognize that learners play an active role in constructing what they hear or read, based on prior knowledge, which may distort even the purest input. Finally, transmission theories have tended to ignore social aspects of learning or limit their role to extrinsic motivation. In contrast newer theories view learning as inherently social, in both process and outcomes.

A situated, social constructivist approach to learning can open new horizons for the application of advanced technology. We will elaborate these implications in later papers in this series and therefore limit our exposition here to some high-level points. First, modern learning theory focuses attention toward the communicative capabilities of technology, especially the support for interactive communications such as conversation and collaborative problem solving, not just viewing or replicating canned multimedia elements. Second, modern learning theory emphasizes the *representational* potential of new technology—the ability to create new animated, graphical conceptual tools that better anchor to students' prior knowledge and bridge to experts' sophisticated view of the subject matter. Hence, these theories suggest moving beyond capture and replay of standard diagrams and illustrations to creating tools for learning that are uniquely supported by the visual and interactive capabilities of new media. Finally, modern learning theory highlights the potential of the simulation and virtual reality possibilities of modern learning technology to close the transfer gap. Computers can present students with simulated problem settings that are a much closer match to the contexts of practice in which they will eventually have to apply their knowledge. Thus, technology-enhanced learning environments can potentially allow learners to begin building a repertoire of

cases that are closely identified with the problems they will need to solve with their clients.

In conclusion, modern learning theory helps us see the revolutionary—not just evolutionary—possibilities of technology for learning. Breakthroughs may be possible, not just in the costs of providing learning opportunities but in the fundamental factors that govern the success of learning. Many new learning technologies, moreover, have embedded these cognitive science principles into their design. In our next two papers, we will show how the use of these technologies provides evidence that learning does not have to happen by accident; learning can indeed be designed to support innovation within companies.

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