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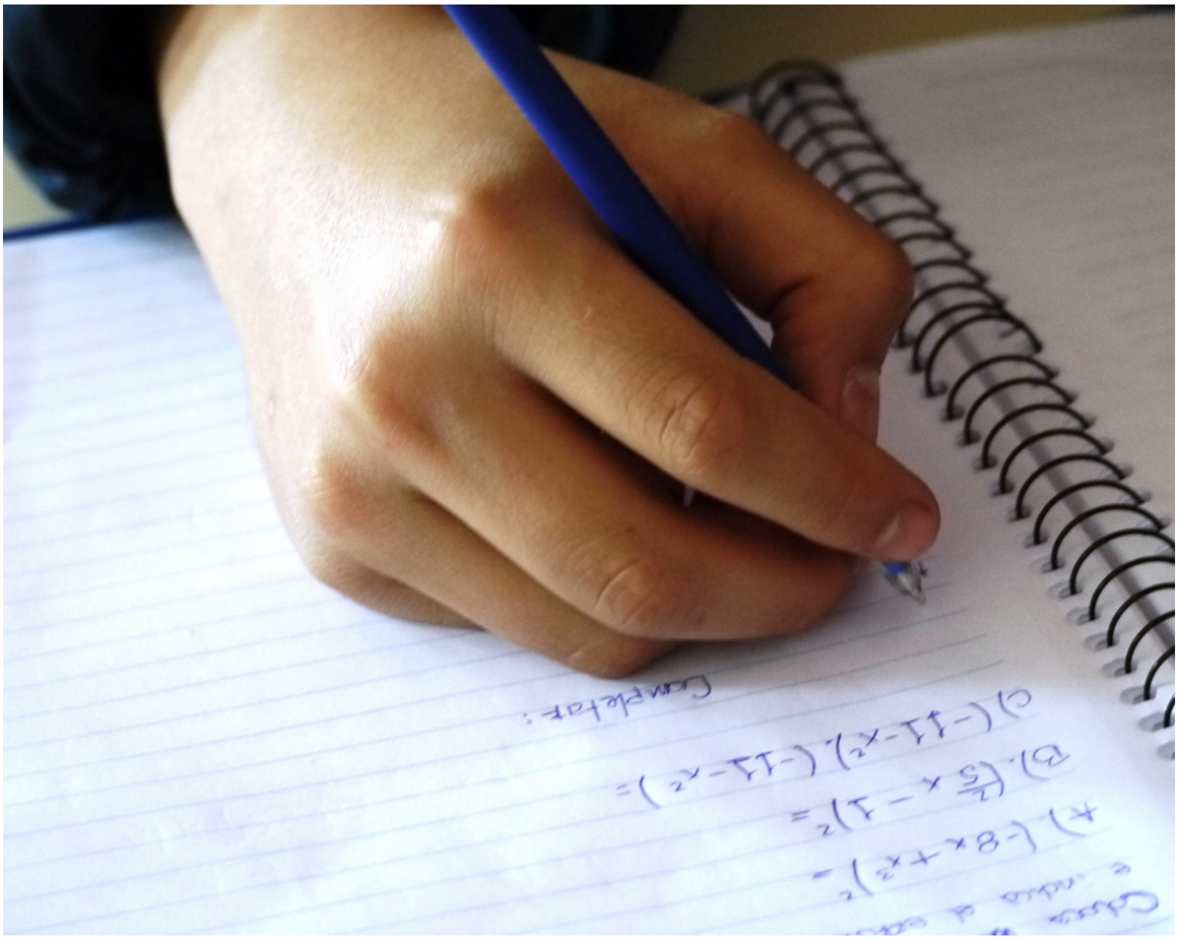
TRAINING THE 21ST-CENTURY WORKER
POLICY ADVICE FROM THE DARK NETWORK OF IMPLICIT MEMORY



Geneva, Switzerland, November 2015

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Training the 21st-century worker
Policy advice from the dark network of implicit memory

by

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Highlights and policy implications

Technological achievements and the globalization of labor require complex skills for the workplace. Companies reportedly demand employees ready to “plug and play”, who are also creative, communicative, and collaborative. Accordingly, international agencies often advise lower-income governments to de-emphasize “traditional” book learning and use innovative pedagogies to teach the needed skills explicitly.

However, memory research suggests that at the population level this strategy this is not feasible. Complex skills are built from shorter chains of component skills. To develop them, this people need extensive practice and feedback. Through multiple trials, individual movements and thoughts are rearranged for efficient execution into longer chains, with minimal pauses between them. The result is automaticity, that is effortless execution with little or no conscious attention. Automaticity allows people to offload tasks from their working memory and thus have time to think about more complex issues.

Skills are furthermore an intricate interplay between two types of memory: (a) explicit memory, which is involved in personal memories and conscious knowledge of rules, and (b) implicit memory, which includes movements, procedures, tacit knowledge. Implicit memory is involved in nearly everything people do, but it is mainly unconscious. We most readily recall our conscious memories and we underestimate the role of the implicit memory. Thus our decisions may be biased in favor of explicit memory.

Limited recall of personal training experiences may result in illusory impressions regarding the speed and ease of training. Donor agency staff may advise governments on the basis of memory biases, particularly biases of highly educated people. Thus governments may be advised to invest in methods feasible for students who already know a lot. One result may be training programs that are skimpy and offer too little practice for average or below-average students. Training may also be conducted in brief time periods that make instruction vulnerable to forgetting.

Possibly because such beliefs about the learning process are self-evident, they are rarely validated through studies or even empirical data collection. Thus, governments and donors are unsure how to proceed in case educational or training programs fail to give the expected results. The cognitive research on skills acquisition has far-ranging policy implications, particularly for complex “21st century” skills. This is applicable to all levels of education, formal and nonformal. A few are mentioned below.

Systemic issues in the education sector are important, but instruction is paramount. International agencies emphasize systemic issues and direct governments’ attention towards management, measurement, certification, and accreditation mechanisms. However, the most important function of schools and other training institutions is to teach the needed skills efficiently.

Instructional advice must be based on memory research. Some policy documents recommend “innovative” pedagogies and direct instruction towards higher order skills, but these get little support from the research, and may exacerbate inefficiencies. Instead, policymakers should focus on instructional details. They should ensure that students are explicitly taught the individual pieces of information or procedures in their programs and that they practice them to automaticity. Curricula should devote time to the essentials of relevant skills. Realistic timeframes must be set to effectively train most learners. Sufficient budgetary resources must be allocated for these functions.

The time and materials needed to teach various programs and subjects require validation with average and below-average students. There is a need to collect data and budget resources on a realistic basis. Attendance, dropout, and success rates should help determine the duration, distribution, and amount of practice necessary to develop stable skills for most learners.

Learners’ prerequisite skills must be assessed and remedied for subsequent success. Educational institutions at all levels should ensure that entering students know the information and procedures required to learn the content that is to be taught and can execute them fluently. Prerequisite skills may include reading, writing, and calculating with fluency and ease. Students with deficiencies must receive remediation before learning the more complex chains that rely on them. (For example, reading engine service manuals). Even in higher-income environments, proficiency should not be assumed.

Training in procedures that rely extensively on implicit memory requires considerable practice, guided through expert feedback. Such instruction is harder than instruction of conscious, explicit memory concepts. Training programs must incorporate apprenticeships and other modes of practicing procedures. Potential savings are possible by researching and implementing schedules of spaced reviews. Lower-income institutions may find such requirements challenging, but there are no known alternatives to memory consolidation.

Teachers must be experienced in actually carrying out the procedures of training programs rather than being able merely to talk about them. Many governments have prerequisites for degrees that exclude those who have actual expertise, such as automotive mechanics. Qualifying vocational and other instructors on the basis of their skills rather than credentials is difficult, but teacher expertise is needed to give students targeted performance feedback.

There is no such thing as an unskilled worker. The skills acquisition process shows that even menial jobs, such as digging ditches or washing clothes, are executed more efficiently with time. In the informal economies, workers with low levels of education acquire most of their skills informally through interaction and observation both on and off the job. This means that certain people may acquire mastery in complex skills empirically, such as complex math through construction skills. Training and employment policies based on designations such as skilled, unskilled, or semi-skilled workers may be misguided. Labor studies instead must consider the actual hierarchy of skills to be mastered for execution of complex skills. This also means that actual competencies must be recognized in various programs of study rather than the acquisition of degrees that often require knowledge peripheral to the execution of relevant skills.

Secondary education policies merit reassessment, given the research body on skills acquisition. The issues, particularly for lower-income populations are multiple and contradictory. Students may enter with limited knowledge and spend time in activities that prevent them from learning informally skills that support locally appropriate livelihoods. The interest in vocationalizing education swings back and forth over the years, but research would imply considerable difficulty in implementing effective implicit learning programs. Furthermore, learning specificity would militate against a broad applicability of vocational skills at the secondary level.

The demands of employers for better-trained workers have been taken at face value and merit some scrutiny. Labor market surveys may include biases about actual hiring decisions and salaries that have been underreported. Various countries and sectors may have more limited needs for complex skills training. More realistic and representative surveys are needed.

Means must be found to train staff of donor agencies and governments on the use of this scientific body of knowledge. Technical expertise must be developed for the many uses of cognitive science in education. The skills gap can only be mitigated by shining a light into the dark network of implicit memory. Without attention to these processes, the decisionmakers' cognitive biases may keep the doors to complex skills for the poor firmly closed.

Introduction: The MIT graduates and the light bulb

It was graduation day in 1994 at the Massachusetts Institute of Technology (MIT) in the United States (Cromie 1997). The new alumni, wearing their academic caps and gowns, were filing out of the ceremony. A young woman approached some of them and politely asked: "If you were given a piece of wire, a battery, and a flashlight bulb, could you light the bulb?" Most of the alumni quickly answered "yes." But when given the bulb, battery, and wire, few could do it. One graduate protested that she was a mechanical and not an electrical engineer.

The ridicule was alive twenty years later in multiple YouTube videos.[1] There has certainly been some pleasure at embarrassing MIT, but scorn at the inability to apply acquired knowledge is not just heaped on the graduates of elite institutions. For example, Nicaraguan engineering students spent a summer helping a village to build waterworks but found that some villagers could do the job better (Reynolds 2014). It seemed absurd that supposedly unskilled farmers would perform better than highly educated students.

Cognitive science can explain this paradox.[2] Cognitive scientists have found that memory is roughly divided into explicit and implicit memory. Explicit, or declarative, memory consists of personal recollections and knowledge of facts. Implicit, or non-declarative memory uses past experiences to perform actions without thinking about them (Zola-Morgan and Squire 1993). Thus implicit memory consists of movements, conditioned responses, and tacit knowledge. It is mainly unconscious, so most of the time we are not aware of its operation. Information can get transformed from one type of memory to another. But the transformation from explicit to implicit memory does not always happen easily or automatically. Plentiful and specific practice and feedback are often needed.

Research on memory functions and their applications is a vast field that has unfolded for decades; some important studies are sixty years old. However, the research has remained a well-kept secret of cognitive psychologists. Education faculties rarely teach memory specifics, so people working in education typically do not know about the above distinction. Ignorance about memory functions has consequences. Governments and donor agencies worldwide are making strenuous efforts to impart complex skills to citizens, particularly in low-income countries. But without knowledge of how an engine functions, it is impossible to optimize its performance; and money may be wasted in the process.

This document attempts to publicize essential research on the relationship between memory functions and skills development and to illustrate its educational and policy implications. Understanding memory functions is also important because

[1] See for example https://www.youtube.com/watch?v=aIhk9eKOLzQ

[2] Cognitive psychology is the study of how people perceive, remember, think, speak, and solve problems. Psychologists have been conducting experiments on these topics since the 19th century. The term "cognitive science" often refers to interdisciplinary research on the mind and mental processes. The term "cognitive neuroscience" refers to research on brain states which directly correlate with mental states (Sun 2008); for such research, neuroimaging methods are typically used.

the distinction between explicit and implicit memory seems to be responsible for significant and systematic memory biases that affect how people think about education. This document therefore also presents the problems and solution attempts made by donor agencies as well as research on cognitive biases of people. It the proceeds to illustrate essential memory functions that have applicability in education. The review includes "non-cognitive" skills, personality variables, complex skills and gender and status issues. It also briefly covers the problems of lower-income vocational institutions and links them to cognitive research. It concludes with policy implications and prospects for future research.

1. 21st century skills and the imperative of quality policy advice

According to the International Labour Organization (ILO), nearly 75 million young people are unemployed around the world, with a projected increase of more than 4 million between 2007 and 2016. At the same time, increasing numbers of young people are entering the labor market, meaning that 80 million jobs will be needed over the next years to restore pre-financial crisis levels of employment (Hannon 2012). Improvements in communications technology and increases in global competition are giving rise to outsourcing and contracting; the substitution of humans by technology is wiping out many routine "blue-collar" jobs in developed countries and is resulting in dramatic shifts in comparative advantage.

Thus, developed economies are becoming increasingly reliant on high-value, knowledge-based assets (Hannon 2012) and on workers who possess complex skills. Such skills include computer programming, engineering design, airplane mechanics, accounting, business management, and many others. The skills must be flexible and adaptable to changing circumstances. Workers must rapidly understand the requirements of the job, use computers fluently, know languages of international communication, and have a good understanding of mathematics. They are also expected to show initiative, creativity, critical thinking and responsibility, communicate clearly and persuasively, understand other people's communications rapidly and "read between the lines," demonstrate good manners, and seamlessly integrate into teams (Wang 2012).

But employers worldwide report difficulties in finding sufficient job-seekers who possess most or all of these "21st century" skills (e.g. Blom and Saeki 2011; World Bank 2011). The scarcity seems to exist in higher as well as lower income countries. In the United States, for example, a poll found that only 11% of employers found recruits who were ready to "plug and play" (Lumina/Gallup 2013). In Thailand, meanwhile, surveys suggest that professionals lack English, information technology, and creativity. Employers there also found deficits in time management, communication, numerical competency, problem solving, social skills, adaptability, and teamwork (Banerji *et al*. 2010:18). This difference between employer expectations and qualified workers available for employment is often referred to as a "skills gap."

The skills gap seems evident in educational results. In many countries 15-year-olds are unable to apply in tests what they have learned (OECD 2014). University surveys reflect a similar perspective; 68% of graduates in a Spanish sample expected difficulties in finding employment due to their lack of job preparation (Garcia Lombardía 2014). Similarly in a U.S. poll, only 14% of recent graduates thought the university adequately prepared them for working life. By contrast, about 96% of college provosts reported that they adequately prepared students for the workplace (Friedman 2014; Lumina/Gallup 2014).

The stakes are high. Globalization implies that skilled workers may be imported from other countries, while less skilled national workers may remain unemployed. Therefore governments find it important to narrow the skills gap. Several international organizations are actively providing technical and financial assistance for this purpose. For example, the World Bank has financed extensive analytical work from the perspective of economics and labor studies in most countries (see, for example, Riboud *et al*. 2007; Fasih 2008; Wang 2012). The World Bank has a core strategy for bridging the skills gap, called STEPS (Banerji et al. 2010). It has also conducted extensive surveys of entrepreneurship training (World Bank 2013b; Valerio *et al*. 2014). UNESCO journals have published relevant articles, such as a 2014 special issue on the learning needs and life skills of youth by the *International Review of Education*.

To gauge the evidence base used by international organizations on learning, the author of this document reviewed about 12 institutional documents on skills as well as many of their citations. A number of them extensively refer to labor market and training policies. The review focused on the references to published or unpublished research that supported various recommendations (some examples of statements found in documents are provided in the Annex).

The documents rarely refer to procedures needed for learning skills (e.g. Groener 2013). Instead, they often treat skills as already acquired and go on to discuss social, systemic, or institutional issues about them. Some offer pedagogical advice. Authors imply that the current methods for imparting the necessary skills are inadequate and urge governments to find new ones (see, for example, Acedo and Huges 2014; Akyeampong 2014). Authors frequently suggest that the new methods be innovative, without defining innovation or showing how innovation would make skills acquisition more effective.

Some World Bank documents, for example, advise governments on how to prepare the population for mastery of complex skills. Education systems should become flexible and responsive to change so that they maximize human resources and equip people with up-to-date skills (Wang 2012). This tripartite model of flexibility, updated skills and employability is expected to eliminate restricted access, skills mismatches, and weak work-to-school linkages.

According to the model, educational institutions must be granted autonomy, must have accountability and must be subject to assessment (Banerji et al. 2010:19). School systems should no longer organize curricula by discipline and give tests on content ("hard skills"; Wang 2012). Instead, they should teach a combination of basic, new and "soft" skills. Instruction would emphasize teamwork, communication and leadership, and teachers would be evaluated accordingly. The examination system and pedagogy must also change to reflect soft skills, teamwork, leadership and communication (Wang 2012:27). Students should work in groups at school so that they can easily integrate into teams at work. Employers should be substantially engaged in training, but learners must have realistic expectations about the market and develop self-learning skills to make themselves desirable to employers (Wang 2012:47-48).

Thus, governments are advised to de-emphasize the instruction of specific disciplines and aim for the larger vision of workers collaborating and communicating to fulfil their employers' expectations. One common belief is that memorization of facts is unnecessary. If workers need to know something, they can just look it up. Given the stakes involved in modifying education systems, such recommendations ought to be derived from research on how people learn. So, is the advice based on learning research? The answers may be surprising.

2. Skills classifications and the potential for memory bias

To understand the rationale of the recommendations, it would be useful to examine how various agencies define "skills" and what types of skills are discussed in various documents.

The variability of definitions is noteworthy. One organization defines skills as "a combinatory form of knowledge that makes use of theoretical, procedural and environmental knowledge, or learning, know-how and life skills, to solve problems, make decisions, carry out plans, etc." (ADEA 2012). Another document includes in the definition "competencies, attitudes, beliefs, and behaviors that are malleable (modifiable) across development and can be learned and improved through specific programs and policies" (Guerra *et al*. 2013).

Documents also classify and discuss types of skills. The schemes similarly show remarkable variety and also overlap. Skills may be divided into cognitive and non-cognitive, or hard and soft (Guerra *et al*. 2013); technical, transferable, and foundation (UNESCO 2012); unskilled, mechanical, routine, and professional (Beeby 1996); routine manual, non-routine manual physical, routine cognitive, non-routine cognitive analytical, and non-routine cognitive interpersonal skills (Levy and Murnane 2003; UNESCO 2012); learning and innovation vs. information, media and technology vs. life and career skills (Fadel 2011); cognitive, affective, and psychomotor skills (Blom and Saeki 2011, evoking Bloom 1956).

Some documents also distinguish between vocational skills and core skills (or general skills). The latter are cognitive/problem solving, social, communication, personal behavioral/ethical, learning (ILO 2007). One striking distinction pertains to cognitive and physical skills. People performing the latter are often considered non-professional, routine, unskilled (see Aedo *et al*. 2013). References to complex skills use the terms "21st century" skills, "catalytic" skills, or "new basic" skills. To perform them, workers ought to possess the "4Cs": creativity, critical thinking, communication, and collaboration (Akyeampong 2014).

Thus, skills are defined and classified in different ways by different authors. Much economic research and policy advice has evolved on the basis of classifications. Without clarity, however, it is impossible to know what various policymakers have in mind when discussing policy. Furthermore, none of the reviewed documents referred to research that validated the skills classification used, such as factor analyses.

So where do the various classifications, definitions, and beliefs about skills come from?

In 2014, the World Bank's World Development Report surveyed the research on common cognitive biases and raised serious questions regarding preconceived notions of staff regarding what should work in development and why (World Bank 2014a:180). Explanations are linked to evolutionary psychology, memory functions, and the need to make fast decisions given working memory limitations (see below). People systematically use certain shortcuts. For example, we tend to estimate the probability of certain events based on personal familiarity (Kahneman 2011:129). We reconstruct events based on our estimate of occurrence. We forget what we forget and thus we tend to believe that what we know is all there is to know (Kahneman 2011:85-87). For example, an economist who attended private schools in Mozambique may vastly underestimate the percentage of students who remain illiterate in public schools.

Due to forgetting and the unconscious nature of implicit memory, we all have a biased perception of our memory functions. Surveys have shown substantial numbers of respondents agreeing with propositions that conflict with expert consensus: memory works like a video camera (63%), memory is permanent (48%), and the testimony of a single confident eyewitness should be enough to convict a criminal defendant (37%). This discrepancy between popular belief and scientific consensus has striking implications from the classroom to the courtroom (Simons and Chabris 2011).

It is probable therefore, that advice about skills is derived not from research but from the personal memories of highly educated professionals. They may focus on their own jobs, react to schooling from their own experiences, and attend to the learning needs of their sophisticated children. Their experiences may lead to personal learning theories. Thus they may give policy advice to governments and donors on the basis of systematic memory biases.

Unfortunately highly educated officials may be biased towards complex skills. The bias may detract the attention of governments to the average and below-average students who make up a country's population. So what would be an alternative source of policy advice? The following sections present the basic principles, relevant research, and implications of cognitive science for skills development.

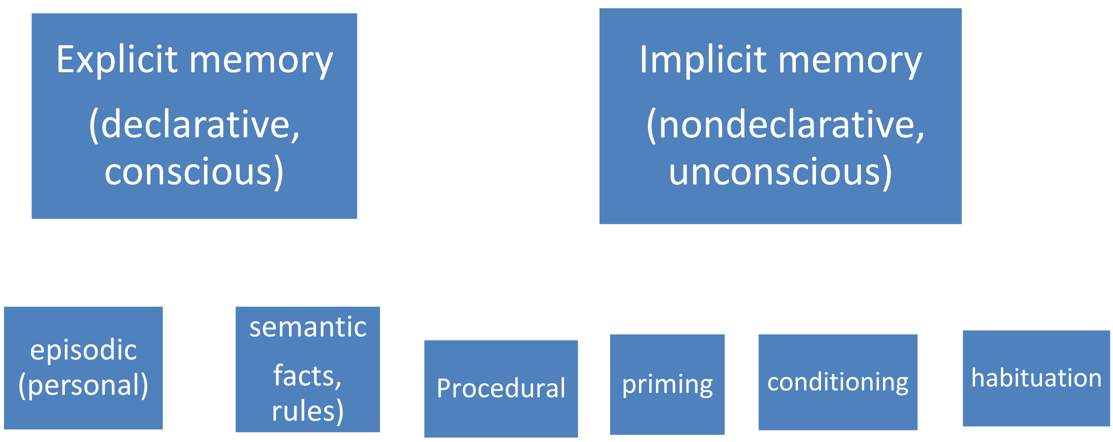
3. Memory basics for skills acquisition

Memory has evolved to help organisms maximize benefits, avoid harm, and survive natural selection. Animals are genetically programmed to process information in certain general ways (Huitt 2003). To learn academic and vocational skills, humans must piggyback on this ancient system and optimize functions that evolved for survival purposes.

Learning has been traditionally defined as *a relatively permanent change in behavior or cognition that is not due to maturation*. It can also be defined as a representation of information in memory, concerning some environmental or cognitive event. In the acquisition of a skill, information items are linked that may already exist in memory. Linkage results from prolonged learning about a family of events (Speelman and Kirsner 2005:27).

Much information starts as autobiographical, episodic memory. Personal recollections repeated a few times create rules, facts, and mental models of the situations where they apply (these are called semantic memory). Schooling enriches knowledge of facts, ideas, meanings, and concepts. For example, you are born with a sense of rudimentary mathematics, but schooling extends the innate concepts to large numbers, teaches efficient operations for determining quantities, and offers complex ways to determine trends of various phenomena. Facts are never loose items, or they would not be remembered. They are embedded in complex networks that help retrieve the information in the circumstances that need it. For example, you forget what happened on the bus two months earlier but you can reconstruct likely events.

Figure 1. Memory types



Source: Squire 2004.

Items in conscious, explicit memory require our attention. We link facts and reach decisions in a space called "working memory." It represents what is in our minds at a particular moment. But that space is very limited; it holds maybe 4-7 information items for perhaps 12-25 seconds (see Abadzi 2012a for a review). This space-time is our processing power. It leaves us no time to think consciously about everything that we do. We must make a few key decisions and let many other tasks run unconsciously. This allows us to perform multiple actions at the same time.

For example, we can play the guitar and sing while reading music. Movements related to the guitar chords have been linked through practice, and notation as well as text reading have been automatized. Our attention can thus go into singing lyrics we may not know and deciding on speed or monitoring the audience. Though we do not pay attention to the reading and the movements, we can modify the actions or stop them at will.

The way to overcome the working memory bottleneck is to pass long chains of actions through it. The chains may then count as one item. This creates a premium for acts or thoughts that are performed in milliseconds (Cooper and Sweller 1987). If some components take longer, people may forget what they were doing; they may get confused, impatient and eventually stop. For example, if you are reading a document and must pause to use the dictionary in every sentence, you may get tired and give up.

Implicit memory alleviates the memory load.[3] It operates in the background of our existence; it is mainly unconscious, so most of the time we are not aware of it. We also cannot easily talk about our automatic actions, unless we retrace them consciously or pay attention to what we do (Reisberg 2013:215-227). We enter an elevator and look for a likely location that has buttons to press; we estimate whether we can run across the street while a car is coming; we know how high to lift our feet to climb stairs; and we do instant mental math without trying. We know how to address people of higher status in our culture. Fishermen, who may be illiterate, figure out how to navigate rivers and open seas (Hutchins 1995).

Conscious pieces of information become the “glue” that links automatized components into longer procedural chains. Factual information and conscious decisions are interspersed with components that are already automatic, like reading, turning bolts, and language comprehension. The final intent drives the decisions, and we have the flexibility to pass from one chain to another, as the goals change. People sometimes call this implicit memory effect “learning by doing.” We may not know consciously what to do, until our movements lead us to the next stage.

Implicit memory encompasses a rather heterogeneous set of effects: procedure performance, such as faucet repair, bike-riding, sensory discrimination, following the steps of a dance, estimations, mental mathematics, statistical monitoring, priming effects[4], sense of familiarity, classical and operant conditioning, dispositions, and habituation to environmental stimuli (Squire 2004; Reisberg 2013:215-227). To form skills from discrete components, we carry out an action, get feedback, and correct errors. If an attempt fails, we analyze the result, decide how to change the next attempt so that success is achieved (Tadlock 2005).

The implicit processes are often more robust than explicit processes in response to distractions, depression, or mental confusion. For example amnesic patients may be more successful in performing implicit rather than explicit memory

[3] It has been argued that working memory is not needed for implicit memory tasks. However this depends on the task. Various studies have shown strong relationships between working memory capacity performance in certain tasks, such as category learning. Greater working memory capacity helps focus on the most task-appropriate strategy and thus underpins performance (Newell 2015).

[4] Priming involves sensitivity to particular stimuli as a result of previous experience. For example, an ad about a product on television may increase the chance that people will unconsciously recognize that product on supermarket shelves at a later time.

tasks (Warrington and Weiskrantz 1982). For these reasons, however, implicit learning often results in knowledge that is less flexible, more tied to specifics of learning environments and often less adaptable to changing situations (Hayes and Broadbent 1988). Relevant academic knowledge, therefore, creates a big advantage in the flexible and efficient execution of skills. Education helps engage in introspection and verbally express some of this ineffable knowledge (Sun *et al*. 2007).

For example, a mechanic who understands the operational principles of an engine do is likely to make different decisions regarding diagnosis and repair than an empirical mechanic who mainly remembers how various parts fit together. A farmer who understands soil composition, microbes, and nutrients is likely to plant, water, and fertilize differently from someone who merely follows the ancestral instructions. By contrast uneducated or little-educated people may carry out complex sequences of movements but may lack the knowledge to understand when or why to change them. Or they may develop theories that are incorrect and reduce efficiency.

In some respects, easy tasks can be learned explicitly, whereas more complex tasks benefit from implicit learning. It is in part because implicit memory keeps detailed frequency counts of various events, and the statistical information can then be used to help explicit processes in various ways. Thus we know tacitly about likely and unlikely events in a particular situation or culture. Implicit knowledge is holistic, offering general impressions rather than analyses. Decisions made by our brain on the basis of implicit knowledge may rise to our consciousness as intuition (Sun *et al*. 2005; Sun *et al*. 2007).

In general if the relations to be learned are simple and the number of input dimensions is small (in other words, if the relations are salient to subjects), explicit learning usually prevails; if more complex relations and a larger number of input dimensions are involved, implicit learning becomes more prominent. For example, complex tasks, such as a game of navigating in a minefield, seem easier to acquire implicitly (Sun *et al*. 2005). Few tasks involve only one type of memory; in most cases, implicit and explicit memory are entwined (Sun *et al*. 2005; Sun *et al*. 2007).[5] Below is one example which illustrates the various types of implicit memory and their interplay with explicit memory. It also illustrates learning rates.

> *Mary must replace a broken sink faucet. An affordable plumber cannot come for several days. She has done similar tasks before, so she feels reasonably confident that you can do this. She lies under the sink and tries to loosen the faucet pipes but she realizes that if she removes the drain pipe first, she will have better access. She turns her wrist to loosen it, but pressure gives her fingers feedback that she tightened it instead.*[6] *The sink wrench is a challenge. Which way to place it to loosen the nuts? How much pressure to apply? Her*

[5] The difficulties in juxtaposing the two memory systems happen to some extent because they inhabit different parts of the brain. The explicit memory system primarily includes the hippocampus and temporal regions of the cerebral cortex. The implicit memory system primarily includes the basal ganglia, the cerebellum, the frontal lobe of the cortex, basal ganglia, and potentially the inferior parietal regions of the cortex (Reisberg 2013).
[6] On motor feedback see Brashers-Krug *et al*. 1996.

eyes and hand receptors try to discriminate in the dim light under the sink. Is it coming loose or is the top faucet moving as well? Eventually she takes off all pieces. Now she takes up the new faucet's installation manual. She can read fluently, so she reads each step effortlessly. She looks for the piece that matches the picture, and gradually assembles the parts.

But not all steps are written. Should she wrap Teflon tape around all bare tube threads? She does not want to turn on the faucet and have water squirt all over. She stops undecided. But the word "tube" primes her to think of YouTube. She walks to her desk, effortlessly turns on the computer, and with her proficiency in background knowledge and search engines, she locates a plumbing video on YouTube. The demonstrator speaks a language she knows well and shows pieces she recognizes. She now has the answer and can retain crucial pieces in her working memory. After another hour of reading-locating-doing-getting feedback, the faucet is installed. It is now raining outside, and for moment she confuses the rain sound with the drip-drip of a leaking tube. Fortunately the pipes stay dry. As she turned on the faucet and saw water running, she picked up the soap without thinking and washed her hands.

Mary worked for four hours but succeeded. Dopamine floods certain receptors in her brain, and she feels rewarded beyond expectations (Schmidt et al. 2012; Schultz 1998). She is even motivated to attempt a failing faucet in the bathroom. That is a different model, and she must learn to distinguish the look of slightly different parts. But the principles are the same. Now she knows the order of removing and replacing, so she will spend less time thinking. She may only need two hours. A professional plumber said he did one of these in 30 minutes. If she wants to get better at this skill, she may spend more time watching YouTube demonstrations, practice with parts, and change all her relatives' leaking faucets. After perhaps 15 replacements, she will carry out many actions automatically, without thinking. She may even chat on the phone as she replaces parts. And her execution time may approximate that of a professional.

The unconscious nature of implicit memory makes it hard to stand out in our minds. It is easier to focus on what we remember. It is easy to forget the many hours spent practicing reading, piano, or certain sports during childhood. We may also forget the hours of homework linking various facts until they became linked into chains of effortlessly recalled knowledge.

These misty recollections may create an "illusion of potential." Vast reservoirs of untapped mental ability supposedly exist in our brains, and leaps of performance are possible (Simons and Chabris 2011). The result may be unfounded optimism and exuberance that complex skills are feasible if schools just focus on teaching the skills that are used daily in the offices of educated people.

Systematic memory biases and the evanescence of implicit memory may complicate the work that countries are trying to do. For example, seeing an employee who shows up on time and takes initiatives to increase company profits, it may be hard to visualize the 10,000 hours of study and parental guidance that shaped this behavior over many years. The components of various skills may not be obvious. The tendency may instead be to teach the performance of the final product, without regard to components. It may be easy to believe that a month-long course will teach flexibility and initiative to unemployed youth.

When influential people have such beliefs, cognitive biases may turn into programs, loans, and grants. Can policies be specified more wisely? The following sections succinctly present research on the main variables and instructional implications of skills acquisition.

4. Some biological aspects of skills acquisition

Research into the detailed aspects of learning has greatly benefited in the 21st century from neuroimaging techniques. These help visualize changes in the cortical structure and function and enable us to understand how the brain changes in response to training.

Brain imaging shows that the brain adapts to the skills needed. Different occupations make different demands on the brain, and the brain makes specialized neural networks in response to those demands. For example, acquisition of movement-related skills, results in changes in the motor cortex and regions related to paying attention and keeping items active in memory. If skilled performance demands rapid perceptual discrimination, the brain will develop networks to support perceiving those patterns (Charness 2006:308; Solokoff 1989). Automaticity is reflected in the subcortical areas of the brain, such as the basal ganglia (Floyer-Lea and Matthews 2005.)

Memory resides in multiple brain areas. These areas are linked into functional networks that are activated when we perform various activities. These networks may not always interact directly. Motor skills are learned in one part of the brain, whereas classroom instruction and information read in a book are acquired in another area of the brain. Once behaviors become automatic, they can be retrieved from areas in the cortex involving conscious control (Helie, Roeder and Ashby 2010).

The operations at the neuron level in our brains offer hints on how learning can be optimized. To create memory, neurons must connect in combinations that did not exist earlier and form new synapses (Ali *et al*. 2013). Neurons become wired up in small groups at a time. Only a few such connections take place at a time. And initially their survival is dubious; a new link between two items competes with existing links. To make new connections permanent, repeated trials are needed, until the relevant neurons involved are linked relatively permanently.

Relative permanence in memory requires a biological process called consolidation. It takes place over several days and transforms novel memories from a relatively fragile state to a more robust and stable condition. Every time a skill is recalled and practiced, it is reconsolidated. New associations may be formed, and the neuronal connections are strengthened. For long-term retention, the practice must be spaced across days, weeks, or months (Stafford and Dewar 2014). Consolidation is enhanced during sleep, particularly during deep sleep, especially when it soon follows the initial phase of memory acquisition (see, for example, Fischer *et al*. 2002). So, a full night (or day) of uninterrupted sleep soon after learning a skill greatly facilitates consolidation (Censor 2013).

Linking and practicing skills chains moves the execution from the conscious effort made by the cerebral hemispheres to subcortical parts of the brain, like basal ganglia. With this brain-level shift, performance becomes faster, less variable and less prone to error (Jansma *et al*. 2001); this stage is therefore thought to represent habit formation, or automaticity.

Mastery results in a brain paradox. It is associated with less rather than greater activation of the regions that are involved[7] (Patel *et al*. 2013). The training process on the other hand, shows in brain-imaging studies much activity in the areas relevant to a certain skill.

Over the longer term, high-intensity or continued practice may show few visible effects. However, the relevant brain regions continue to be remodeled through practice and show increased plasticity (Sampaio-Batista et al. 2014). Even after the asymptote of the learning curves is reached (see below), overlearning may continue, and tasks may become more resistant to forgetting. Often the tasks that induce the most errors during acquisition are the ones that create the most stable long-term improvements (Soderstrom and Bjork 2015). An overlearned task may withstand time and the onslaught of subsequent information, and be less likely to be forgotten; and people do not lose control of automatic functions.

5. Composing skills from the bottom up

Often a skill starts with information bits from explicit memory. For example, in a music class a teacher points to notes on the blackboard, and children transpose them one by one into notes on their flutes. After a few trials, the note-by-note performance becomes fluent. We can read manuals on how to do certain actions, and point by point we can execute them. We can also undertake chains of action that require more thinking between the various links, using information that comes from higher levels of education.

To compile, compose, and produce automatized units, explicit instruction helps. Learners roughly go through a conscious cognitive phase, an intermediate associative stage, and an autonomous phase (Fitts 1954). In the early stages of acquisition, execution is controlled by conscious actions that are held in working memory and attended in a step-by-step fashion (Anderson 1983 and 1993; Proctor and Dutta 1995). The needed information must rush into working memory rapidly, otherwise we may forget what we were doing. For example, when someone is

[7] Training results in decreased activity in brain regions involved in effortful control and attention that closely overlap with the control and attention networks. Increased activity was found after training, however, in the default-mode network that is involved in self-reflective activities, including future planning or even daydreaming. Thus, skill mastery is associated with increased activity in areas not engaged in skill performance, and this shift can be detected in the large-scale networks of the brain. Essentially, the more adept we become at a skill, the less work the brain has to do (Patel *et al*. 2013).

taking driving lessons, every movement and decision must be made consciously. Often rudimentary problem-solving methods, such as analogies,[8] are useful.

People commonly believe that "practice makes perfect." However, practicing exactly the same movements or processes does not improve skills. The important variables are timing and nature of feedback (Ashby and Maddox 2005). With multiple trials, errors are detected and eliminated. Then transition time from one movement to another is minimized. The sequence of actions is rearranged to minimize time and effort, and the chains of actions are executed smoothly, fluently, rapidly, effortlessly.

If one of the links fails, the entire task may be aborted. If an aspiring mechanic reads haltingly, has limited vocabulary in a certain language, or searches the computer slowly, the working memory would lose the information needed for the next step. The job would take 12 hours instead of four, and many people would just abandon it. Or it might be completely undoable. For some professions, fluent execution of long chains is critical. For pilots or doctors who must make split second decisions, automaticity has life or death consequences.

Longer and complex chains of skills can only be developed after smaller chains have been formed through practice and use (Keele 2005; Schmidt and Lee 2005; Speelman and Kirsner 2005).[9] The number of basic movements that can be linked into longer chains at one time is probably limited by attention and working memory span. The more skills are practiced the more resistant they become to forgetting. People can perform them consciously if needed and pay attention to what they do. Paradoxically, however, their performance may suffer, and under excessive pressure, they may "choke" (Beilock and Carr 2001).

Eventually novices may become experts and masters of their skills. Practice reconfigures memory networks to operate efficiently and automatically. Experts categorize problems differently, construct mental representations of problems, search efficiently for the appropriate problem-solving operators, retrieve them, and evaluate progress. These schemas of categorized knowledge include additional information not available to novices (Chi *et al*. 1981). Thus, expertise can be decomposed into a set of knowledge structures that are learned. Learning environments can be structured to facilitate its acquisition (Nokes *et al*. 2010).

Awareness of the stages and purposes of the learning facilitates consolidation (Robertson et al. 2004). It therefore appears useful to teach students how they learn and to encourage thoughts about what effects they see as a result of study and practice.

Learning curves and skills acquisition trends. Skills are not acquired at a constant rate. Initially progress is rapid and shows much behavioral change. Then a long period of slower progress follows. Reaction time in the first few tries drops a lot performance fluctuates in the short term. With more practice, reaction time levels off

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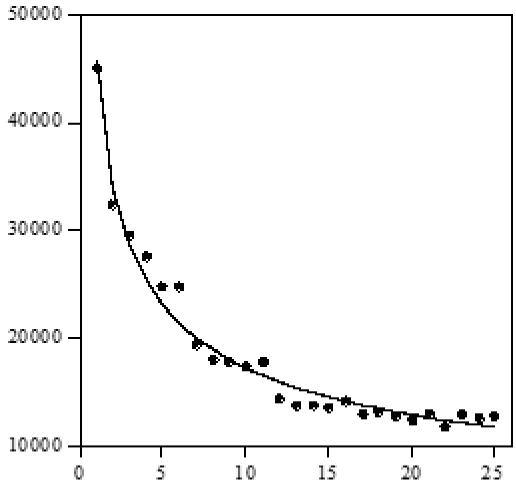
[8] Problem-solving methods such as analogy (possible through statistical learning) may be considered 'weak' but they facilitate compilation of items into skills chains.
[9] "Productions" is a term often used instead of chunks for procedural knowledge (Speelman and Kirsner 2005).

and performance stabilizes. Then behavioral change may be almost unnoticed, but consolidation of previously learned content continues. Over the long term, the trend roughly resembles an L and is called a *learning curve* (Speelman and Kirsner 2005; see Figure 2 below).

"Learning curve" has become a common expression that often conveys effortful learning (e.g., "a steep learning curve"). However, the commonsense use misses the changes in learning rate and effort that are inherent in this process.

Figure 2. A learning curve depicting the effects of trials over a period of days

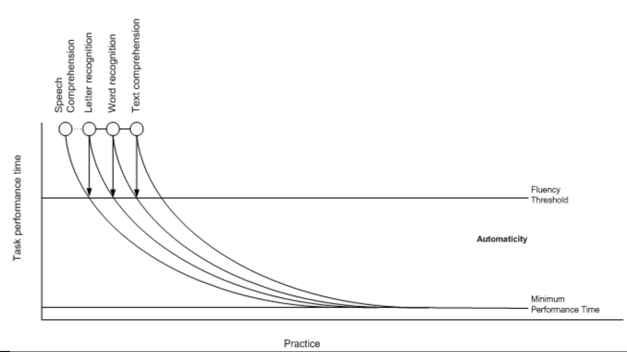


Source: Speelman and Kirsner, 2005 (reprinted with permission).

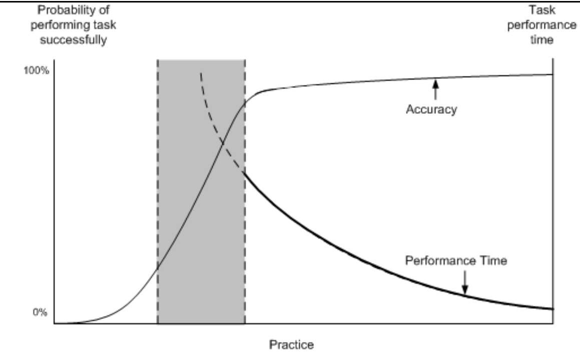
In the late 19th century, it was discovered that learning curves obey certain mathematical functions. Overall, performance at a particular point in time can be roughly predicted from prior performance, the number of components in the task, the amount of practice, and the learning rate.[10] The mathematical functions connect learning observations to certain universal laws.

[10] The performance time that is associated with learning is called the power law of learning. The general form of the power functions is given by the equation: $T=X+NP^{C}$, where T represents the time needed to perform the task, P represents the amount of practice in the task, X represents performance time at asymptote, N represents a constant proportional to the number of processing steps involved in the task, X+N represents the performance at trial 1, and c represents the rate of learning. C is a parameter of negative acceleration. It is, commonly in the range $-1<c<0$, but can be positive when acceleration is positive, as in the case of increasing accuracy. Some tasks may be better described through an exponential function, which is $T=X+Ne^{cP}$. However, practical differences may be small (Speelman and Kirsner 2005:78). In some tasks, such as chess playing, improvements may come after a delay of several years, highlighting little-understood cognitive changes (Gaschler *et al*. 2014).

Figures 3 and 4. Compiling and accuracy in a hierarchy of skills
(*Source:* Speelman and Kirsner 2005, reprinted with permission)



How components of skills are linked: Processes that operate at one level of analysis provide the structures for operation by processes at the next higher level of analysis. The circles present groups of processes involved in performing particular tasks (Speelman and Kirsner 2005:122-123).



Early in training, the probability of performing a task successfully is 0% initially. The S shape represents the realities of preparing for a new task. Performance time starts slowly and approaches the asymptote with practice (Speelman and Kirsner 2005:129).

Learning curves can also represent the acquisition of complex tasks (see Figures 2 and 3 above). When a task involves old and new components, the task will be learned at a slower rate than that at which each of the two sets of components improves. This learning rate will be moderated by the relative number of processing steps between old and new components of the task, and by the amount of practice that the old skills had prior to learning the new task. Learning curves that represent improved performance on a task in effect reflect summaries of learning curves of component skills.

Different skills show different learning rates, and some are clearly easier to acquire than others (for example visual discrimination is easily learned). There are some variations which indicate that learning processes are not yet well understood. For example, under chess players may show sudden improvements after years of modest performance. Such nonlinear models are the domain of the Dynamical Systems Theory and more individually determined patterns, such as non-linear pedagogy (Lee *et al*. 2014). Overall, particularly considering large populations, however, learning curves reasonably depict the skills acquisition process. It was also found that forgetting shows the same trends. Hundreds of studies have been undertaken on learning curves for various tasks, and they tend to show significant uniformity and predictability (Speelman and Kirsner 2005). Applying these helps predict trends for values at which observations do not exist.

Learning curves have been used by industrial engineers and psychologists since the 19th century. For example, they helped monitor the performance of Cuban cigar rollers, whose time still improved after rolling 10 million cigars for seven years (Crossman 1959). Interest in learning curves declined as engineering processes became less dependent on manual labor. However, they are very useful in predicting performance levels given various training parameters and in comparing various populations of the world in simpler skills components. For example, it may be possible to estimate reading or math performance given practice amounts and prior knowledge. Optimal course duration and budgets can be also estimated. However, this obscure domain of psychology must first become known to education staff of various agencies.

6. Research insights into skills acquisition

What happens as people are in the process of learning a skill? Some research findings help clarify common preconceptions.

Instructional practices may have different effects on short-term performance and on long-term retention. Training must focus on optimizing long-term retention rather than short-term performance (Soderstrom and Bjork 2015). Below are some research findings on training efforts.

Strangely, *training may not appreciably change the speed of individual actions*. As mentioned earlier, the changes produced by practice shorten the thinking time between two components (this thinking time is called latency). Practice and feedback rearrange the task to minimize conscious thinking and to reduce the number of needed decisions.

Movements and thoughts do not improve in isolation; they are accompanied by perception. For example, pointing a gun to a target and choosing a moment to shoot become skill components that are inextricably linked. Perception changes frontal motor areas of the brain and may thus contribute directly to motor learning (Vahdat *et al*. 2014). For this reason, *experts in a skill surpass less expert people in recognition rather than production skills*. This means that training of psychomotor skills should incorporate recognition skills early in the acquisition process. For example, a football quarterback should practice “reading” defenses while practicing footwork drills. As a result, sports training favors decision training over action-related training (Vickers 2007). Athletes can be trained to recognition various situations, and that leads to improved performance of the overall skill (Williams *et al*. 2003).

Despite the general skills acquisition features discussed earlier, progression to higher-level skills has some additional complexities. Practice and automatization of simple tasks does not always lead to mastery of complex motor tasks. It seems that situations with low working-memory processing demands benefit from practice conditions that increase the load and challenge the performer, whereas practice conditions that result in extremely high load should benefit from conditions that reduce the load to more manageable levels (Wulf 2002). This may be applicable to classroom situations where students are expected to perform very well in certain activities before they progress to others. Low processing demands may include learning very well to add two-digit numbers before moving on to three-digit numbers. Well-to-do students who have benefited from much practice and preparation throughout their lives may also have lower cognitive loads and can benefit from more challenging conditions. It is important to understand better how students’ working memory handles various loads, given prior knowledge, and adapt instruction accordingly if possible.

Challenging practice may help some people improve skills and thus become able to tackle more demanding jobs. For example, technicians who read brief texts for work may also read the newspaper and gradually become able to extract gist from more complex documents. A barely literate stonemason using practical math can automatize chains of skills taught in secondary school algebra, and if shown the analogies, could transfer learning to formal math. An intelligent person, open to experience, willing to study a lot could build on the discrete performance skills, automatize the math operations and potentially become an engineer. Thus there are alternative roads to automatizing high-level skills, through exercise and expertise in tasks involving lower-level components. However, these are complex procedures that are rather rarely accomplished outside formal education.

The extent to which practice results in complex implicit memory has been sometimes underestimated. One example was research involving avid horse-racing followers; they were able to use sophisticated multiplicative models to predicting which horses would win races. The unconscious algorithms they use seemed unrelated to intelligence (Ceci and Liker 1986).

The extent to which practice can result in sophisticated implicit memory needs to be understood better. It sometimes implies that complex skills may become accessible to those who are interested, even though they may not possess the explicit conceptual prerequisites, such as mathematics. For example, FabLabs is a personal fabrication methodology that originated from MIT, which teaches people how to build almost anything. The skills that are being developed in this case are focused visualizing, conceptualizing, and coding. The actual material is produced by programmed machines and 3-D printers. FabLabs has been active in low-income countries, and it is creating a new concept of practical engineering, which skips many of the academic requirements.[11]

The many dimensions of skills acquisition demonstrate a learning model that is a very different model from the static skills classifications conceived by economists.

One implication from this body of research is that *there is no such thing as an unskilled worker*. Even the lowliest jobs, such as digging ditches or washing clothes are executed more efficiently with time. Efficiency increases until people become dexterous, expert in certain skills and execute them with minimal time and energy. Experts recognize instantly patterns that novices do not see and fluently perform the needed actions. In the informal economies, workers with low levels of education acquire most of their skills informally through interaction and observation both on and off the job and do not deserve to be called unskilled (Hagan *et al*. 2014).

This research also has some social repercussions. Many training programs have prerequisites that may be peripheral to the subject matter. These may include complex cognitive tasks, such as knowledge of algebra or foreign languages or prior degrees. However, *dexterity in a task requires only the automaticity of the relevant component skills*. People routinely perform feats of implicit memory, from acrobatics

[11]See: http://www.boston.com/news/globe/ideas/articles/2005/01/30/how_to_make_almost_anything/ and http://www.fabfoundation.org/

to navigation and complex machinery repairs. Numerous work-related skills require mainly movement dexterity with a modicum of conscious decisions. Students who are unwilling or unable to perform complex thinking tasks like algebra, can still perform tasks involving complex movements, minute distinctions, and spatial configurations. Peripheral requirements may stop students from entering or achieving certification in programs that they can perform given the chain of required knowledge.

Entrance to various educational and training programs is typically limited through formal diplomas and prerequisite degrees. These may serve political and financial reasons. However often only a subset of the requirements are truly prerequisite to the acquisition of certain skills. To alleviate various systemic inefficiencies, it is useful for governments and donors to define precisely the prerequisites for various training programs and to make it possible for those who lack the official degrees to enter. Opening programs to those who possess the truly prerequisite skills may increase efficiency and performance.

7. Training schedules and implications of spacing practice

The biochemical mechanisms that underlie memory consolidation create certain conditions that must be respected when people try to learn various skills. One of them is the timeframe used to present stimuli. Learning and reviewing material along longer timeframes increases the probability of permanence compared to brief training courses (Bahrick and Hall 2005).

Another feature affecting consolidation is related to the schedule of exposure to different task variations (contextual interference, see Speelman and Kirsner 2005:75). Practice in regular blocks of time results in faster acquisition but lower recall. The probability of long term retention increases if a task is practiced at random intervals with other intervening tasks (Kantak *et al*. 2010; Carvalho and Goldstone 2014; Ballarini et al. 2013). This finding holds for older as well as younger adults (Lin *et al*. 2010). One possible explanation for this effect is that regular practice results in a smaller and specific number of procedures to be undertaken. By contrast random practice requires a search for more procedures. Trainees have to work harder to access the motor program for a task performed randomly compared to one performed repeatedly. School schedules by definition provide blocked practice. The schedules may create efficient organization and management of school resources, but the effectiveness of the learning is reduced.

These learning effects suggest that critical incidents improve performance (Memmert 2006). They may lead novices to searches that connect large numbers of knowledge items in various parts of the knowledge network. For example, auditors must develop professional skepticism through critical incidents; otherwise they make uninformed judgments (Grohnert *et al*. 2014). These incidents may thus connect relevant information, bring about rapid recall, and ultimately change the way people think about a task. By contrast, many routine repetitions may marginally decrease the amount of time used to carry out a task but may not raise performance to the next level (Wulf 2002; see also the role of cognitive demands, above).

The research on skills acquisition has resulted in recommendations for deliberate practice. For example, musicians and athletes must spend hours a day perfecting the sequences and timing of their skills. Reading requires practice to attain automaticity. But as a general strategy, deliberate practice may be oversold (Macnamara *et al*. 2014). People tend to practice the skills they feel capable of doing, so the same numbers of hours may give different results to different people. According to one study, deliberate practice explained 26% of the variance in performance for games, 21% for music, 18% for sports, 4% for education, and less than 1% for professions. So it benefits skills that are most predictable and has the lowest effects on skills that involve many conscious decisions (Macnamara *et al*. 2014). For the latter, interleaved practice and critical incidents may provide greater advantages. Curricula and teaching activities should somehow incorporate these findings.

8. Transfer of learning and the trap of learning specificity

People often expect that learning under one set of conditions will be recalled under another. Skills are also often expected to be generally available; that is, once acquired, skills ought to be performed under most circumstances. Governments invest funds under these expectations, and trainees similarly invest their time with such expectations.

However, skills often do not generalize. We may not easily recall everything we know about a situation, even if we do have relevant information somewhere in our brain. What is important is the similarity between how the target information is initially processed and the processes that are invoiced during some later testing situation (this is called encoding specificity or sometimes learning specificity; see Tulving and Thompson 1973). The *retrieval path* is important; we recall an information item through the items and sequences pathways used to encode it. If information is demanded out of this encoding context, it may not be recalled.

Specificity in learning tasks may arise because different components of a skill are controlled by different parts of the brain. This may also happen because few neuronal connections can be changed at a time and learning takes place in small chunks. Various skills show the effects of learning specificity. For example, correlations between various motor tests are often modest or low (Bagley 1901; Seashore 1940; Buxton 1938; Seashore *et al*. 1940; Nance 1948; Drowatsky and Zuccato 1967; Haga *et al*. 2008). Practicing arithmetic multiplication does not necessarily improve performance in addition.

Overall, practice tends to improve performance in specific tasks (Hands *et al*. 2006). Skills depend on practice or training that fine-tunes the specific neural subsystems associated with those tasks (Haga *et al*. 2008). Furthermore, the thinking processes in superficially similar tasks are not generalizable. Removing plumbing tubes does not prepare someone to remove the tubes of bicycle tires; the physical principles and cognitive components are different. Similarly, knowing how to type does not facilitate piano playing. Nevertheless, these repairs are performed using hands, and these carry out a finite number of movements. Muscles get strengthened, leading to some efficiencies, and some movements constitute the base components of many skills.

Transfer of learning is a complex topic with hundreds of studies, yielding different results in different domains. Encoding specificity creates obstacles. Knowing one skill can facilitate the acquisition of another, but it can also impede it or have no effect. Overall, it seems that transfer depends not on the inherent nature of the skills but on the features of the environment in which the performance takes place. The degree of similarity between task conditions determines the extent to which skills can be modified to suit different circumstances (Speelman and Kirsner 2005:63). Furthermore, the speed with which a task is recalled depends on the similarity between the conditions of learning and of retrieval. In this respect, therefore, a work environment that is very different from the training environment may inhibit or delay recall of the skills.

The way a task is taught and practiced may influence the degree to which people can perceive similarities with other items. In performing a task is there anything about the performance of one item that can benefit the performance of another? If so, general transfer will occur. This is known as functional equivalence (Speelman and Kirsner 2005:73). Otherwise, only specific transfer may occur. Also, the greater the variation in training stimuli that people are exposed to during training, the more likely it is that they will develop generalized skills. For example, subjects practicing a skill with a smaller number of items acquire more specific skill than subjects practicing with a larger number of items (Speelman and Kirsner 2005:74).
Nevertheless, experience with certain tasks may improve the performance of subsequent tasks. For example, the movements and decisions inherent in videogames transfer into precision needed for surgery and astronautics. Surgeons who played videogames were 27% faster and made 37% fewer mistakes than nongamers (Rosser *et al*. 2007).

To facilitate learning transfer, it is useful to teach the principles of certain skills along with analogies to a new situation. For example, electrical circuits can be shown as analogous to water flowing from a faucet. Transfer can also be enhanced when both acquisition and test materials are processed in a similar manner, for example in seeking solutions to problems. Nevertheless, the processing similarity leading to enhanced access is specific to particular acquisition and test items, rather than a general problem solving set induced at acquisition and at the subsequent testing situation (Adams *et al*. 1988).

Learning specificity poses considerable training challenges. It is not sufficient, for example, to show trainees how to operate one type of equipment and expect generalized application or permanent recall. It is also unrealistic to teach in a training institution and expect easy recall on the job.

Other things being equal, employees who are already fluent in performing an employer’s tasks might be preferred for hiring. But optimization for the employers’ precise tasks seems unlikely. Procedures and environmental conditions will differ to some extent. Even when mature, experienced recruits are hired from similar industries, they need some time to learn the new corporate procedures. Therefore employers cannot realistically expect to hire workers who can “plug and play.”

Corporate training is a necessity. Often personnel officers focus on hiring people who have precise experience for needed jobs. But transfer of learning research implies that it may be preferable in some cases to hire workers who understand the principles behind certain job functions rather than those having specific experience in some narrow domains.

9. Adaptive imitation: A shortcut to skills acquisition

Animals have evolved the ability to learn how to perform by watching other members of their species carry out various movement sequences. This mechanism helps transmit information efficiently and without a need for language.

Hints of this ability were presented in the social learning theories of the 1970s, which emphasized the effects of watching others perform (Bandura 1969). Subsequently, mirror neurons were discovered in the brains of primates. They suggest that human and animal brains contain areas specializing in repeating various actions with intention and areas devoted to planning and future-oriented thinking (Rizzolatti *et al*. 2002). It thus becomes possible to follow sequences of movements, like steps of a dance. When these mechanisms are used appropriately, behaviors can be easily modified (Dowrick 2012).

Step-by-step demonstrations in slow motion, therefore, facilitate learning (Ali *et al*. 2013). They permit movements to be held in working memory and considered. Thus, video training has been shown to be efficient in various contexts, including sport training (Fadde 2006). For example, video training in baseball pitch recognition has been associated with significantly better batting averages for college baseball players. The part-task approach has implications for enhancing perceptual decision-making in sports and areas such as emergency response, vehicle operation, and use-of-force training (Fadde 2006). Similarly, visualization enhances training performance, particularly when the same neurocognitive processes underlie imagery and actual movement (Wright and Smith 2009). For example, trainees may be asked to visualize themselves carrying out training tasks.

Adaptive imitation extends in domains that are often not well understood. For example, people learn managerial activities by watching others perform them (Le Clus 2011:10). This raises a need for greater care regarding the stimuli available to people. Violent movies and videogames have proliferated, and children may spend a lifetime watching these. Considerable research points to the likelihood of acting out violent acts as a result of violent movies and videogames (Bandura 1969; Anderson *et al*. 2007). Most young people are not influenced, but some may have genetic susceptibility (Nilsson *et al*. 2014).

One little-studied and little-understood phenomenon of adaptive imitation is feedforward (Dowrick 2012). People have the capacity to see an edited video of themselves performing skills whose components they can perform but they cannot yet perform the entire chain. Watching such edited videos for several times over a few days helps them produce the behaviors they could not perform. Rather than faithfully imitating, the subject is able to do 'mental time travel' and see oneself in the future performing a certain act. Such video editing techniques are sometimes used in special education and also by elite athletes. For all practical purposes, individual videos are rarely feasible. But videos of models may also be effective; people are more likely to imitate the behaviors of someone with whom they share the same goal (Ondobaka *et al*. 2011). Action chains could pause in certain places to create chunked components (Agam and Sekuler 2008). However, the “dosage” needed to optimize this function must be determined.

The ability to imitate adaptively models of future attainment may explain some aspects of skills acquisition. Young people may be attuned to gender-related behaviors. Showing interest, watching, trying out movements may speed up skills under these circumstances. The capacity to imitate sequences surely has limitations in terms of length and number of repetitions needed, but these have not been researched. This is a fertile area for potential gains in speed and ease for various skills, including teacher training. Nowadays, video is relatively easily produced and accessible, and targeted research is needed in its use. The “dosage” needed to optimize this function must be determined.

10. Social and motivational aspects of skills acquisition

We perform daily a vast array of behaviors that result from formal or informal training. Several factors contribute to performance: ability to direct and maintain attention to a problem, relevant prior knowledge, good working and long-term memory, and ability analyze problems and work to solutions. Thus there are environmental, individual, and task factors that might constrain or facilitate skills acquisition (Newell and Rosenbloom 1980; Thomas and Knowland 2009). Each has its own degree of importance based on the content and the intended goals of the performance. Social and motivational variables may play a role.

Human actions are intended to fit cultural situations and performance demands, often in conjunction with other people. For example, in the mastery of a cognitive task such as learning to read, the cognitive processes involved are not solely individual; they are distributed among teacher, student, and other cultural artifacts employed in the activity (Cole and Engestrom 1993). This phenomenon has been called situated learning (Eraut 2004; see Le Clus 2011 for a review).

Interest in the social aspects of learning has resulted from observations that much learning takes place informally, in everyday settings. Group interactions may facilitate it in multiple ways. People learning in groups may offer information and feedback to each other (Williams *et al*. 2010). Some people remember one item and others another, so when a group collaborates, the entire chain may be reproduced.

For example, studies of coal miners and workers in other industries showed that in the informal learning setting of the workplace, effective learning resulted from learners’ engagement in authentic activities, guided by experts and by interacting with other co-workers (Billett 1993). Although learning was unique to each co-worker, it was also shaped by workplace culture. These observations have raised the importance of nonformal and informal education vis-à-vis formal, degree-based education.

Many articles and books exist on situated cognition, and distributed cognition models have been discussed (see Karasavvidis 2002 for a review). This interest has resulted in slogans such as "learning is social" and emphasis on group work. But the memory mechanisms involved have rarely been discussed. Memory is still an individual process, and in 2015, it was still not possible to share the contents of peoples' long-term memory. Learning in teams raises concerns about capacity to execute individually. Reliance on social groups for answers reduces a need for independent analytical thinking (Rahwan *et al*. 2014).

Also, much learning takes place on an informal basis, as animals have had to do for survival. But informal learning by necessity involves information items or processes that can be retained with limited rehearsal. Extensive amounts of information and complex multi-stage procedures may be more effectively studied in formal or nonformal training events.

The role of motivation in learning involves some of the same variables. It is commonly understood that people who are somehow motivated to learn, do so. However, motivation may not by itself improve learning (Nilsson 1987); information processing variables are needed. Someone who is motivated to learn a certain skill is more likely to practice for longer periods (Baddeley *et al*. 2015). Also motivated persons may attend to a stimulus faster, engage their attention longer on what they are doing, and spend less time to off-learning tasks. They may also engage in more covert practice, that is mental rehearsal (Speelman and Kirsner 2005:105). They may retain related items and thus be more likely to remember new items taught. Also emotional connections linked to motivational reasons may facilitate consolidation. Overall, the effects of motivation seem mainly linked to practice.

Feedback and reinforcement are variables related to motivation. They focus attention and help individuals establish which stimuli are important to them. Therefore, skills may be learned equally well with or without a reward. But the prospect of a financial reward helps retain skills longer (Abe *et al*. 2011).

As with other topics related to learning, motivation is a term used casually, without a recourse to research. Teachers and students, for example, may be labeled as "unmotivated." But it is difficult to infer motivational processes. Issues casually attributed to a lack of motivation may reflect learning difficulties, such as a lack of automaticity for certain skills. Some chains take up too long to execute and burden working memory; students may perceive a low probability of executing them, so they become "unmotivated." This is one more source of confusion which creates difficulties in skills acquisition for lower-income students.

The confluence of social and motivational aspects of learning may help explain some phenomena that have become worrisome worldwide. Groups of men seem to train effectively through informal demonstrations and become proficient in motor skills involving various illegal activities. They may become proficient in weapons use, hacking, burglaries, or drug trafficking. Facility in acquiring skills may exacerbate activities such as civil attack and crime (Adams 2008).

Participants are often educated and can easily learn the relevant explicit information. The extensive production of movies and videogames that show use of weapons may facilitate skills acquisition. In some cases, apparently criminal organizations organize training programs (Clifford 2015). To deal with these social problems, it is important to understand better the evolution of these young men's skills, from low-level items to the more complex skills (amount of practice, training timeframe, feedback, and outcomes.) It is also important to understand the role of comrades in offering information, and the role of video examples.

11. Memory features and implications for skills testing

In attempts to measure the skills gap, donor agencies have embarked on skills assessments. OECD and the World Bank have given skills tests to large samples to assess various countries' competencies for complex occupations. The OECD has a Programme for the International Assessment of Adult Competencies—PIAAC (OECD 2013a and 2013b), and the World Bank has the STEP Skills Measurement programme (World Bank 2014b). These tests mainly focus on proficiency for reading, writing, numeracy, and untimed problem solving in technology-rich environments. About 166,000 adults aged 16-65 years in 24 countries/economies participated in the PIAAC survey at considerable expense (Sorui 2014). Most of these tests are not timed. The documents suggest that competencies are assumed to be stable.

Tests measure what people can recall within milliseconds, given the match between test questions and the way answers are encoded in their memory. However, underlying assumptions may not be well matched to reality. Some issues are summarized below.

Mere existence of information in one's knowledge networks is insufficient. The information must become available to the working memory of a test taker and must furthermore appear in milliseconds. However, the tests were not timed. At any rate, execution speed would depend on participants' location on their learning or forgetting curves at that particular point in their lives. That would be predictive of improvement should they be hired to perform jobs with complex skills.

To be measured, the skill that is tested but have become generalized (e.g. as would be demonstrated by reading fluency), or the test conditions must match the encoding conditions sufficiently. However, encoding specificity may influence test outcomes—particularly tests that demand skills. The test conditions necessarily bear little relationship to the work conditions or to prior study conditions. People may know a lot that may be retrievable under work conditions but is not instantly retrievable under test conditions. (Conversely, people may have learned to retrieve knowledge under test conditions but not in other circumstances.) Performance probability but also recall and execution speed would be dependent on such features.

It is possible that testing various low-level items would predict performance on more complex skills that depend on them. It is unclear, however, how these have been identified. Also only a subset of skills realistically usable at work can be tested by various tests, and these may not be the most important. It is also unclear whether people would rely on a particular item to solve a problem. We all have multiple strategies available for going about our work, and if we forget something or we become too slow, we switch. The outcome may not necessarily be negative or inefficient (Thompson *et al*. 2014).

The stability of skills moment is also of some concern. Abilities are in flux, and day-to-day performance is a result of the constant interplay between change and adaptation (Thompson *et al*. 2014). One-time testing cannot inform where the participant is in the learning or forgetting curve; it cannot predict whether a participant will access the information in the long term. Long-term learning must be distinguished from performance that can be observed and measured during instruction or training.

Test results have engendered much discussion in various countries on what students know. Some governments pay much attention to the outcomes of national and international examinations. For skills tests, countries have been ranked on the basis of the results, but the meaning of the measures has been somewhat controversial. It remains unclear how skills tested with paper and pencil translate into job performance gaps under workplace conditions (Perez-Peña 2013).

Overall, validity and reliability issues could be better informed through learning research. Better choice of predictor and criterion variables could be made. Also certain parameters could be predicted from the learning curves research, and models could be tested against predictions. Then results might be more interpretable, more useful, and less controversial.

12. Lifelong learning: Age-related variables in skills acquisition or execution

Lifelong learning is an essential objective of the Education 2030 agenda and of the Sustainable Development Goal for education. Circumstances in all countries change, and people may have to be retrained for different professions in their lifetimes. Documents by international educators imply that the opportunities for learning throughout the lifespan are limitless, and they focus on global visions, opportunities, and challenges (e.g. Majhanovich and Napier 2014). Few if any documents discuss evidence regarding the brains' ability to learn at various times in life (e.g. Knowland and Thomas 2014).

So to what extent can young adults, middle-aged or older people learn new skills fluently?

The research has some good news and some bad news. The good news is that neural plasticity exists; new neurons are made in the hippocampus and other areas throughout life. In principle, higher-order skills can be learned at any time. However, automatizing chains of skills and learning new motor tasks involves certain limitations. These mainly involve two sources: (a) sensitive periods and biological changes during youth, and (b) reduced neuronal plasticity and deterioration of the nervous system in adulthood.

Sensitive periods. Implicit learning mechanisms are more mature in children than explicit learning mechanisms, and children can be taught motor and perceptual procedures most easily (Ferman 2014). During child development, certain neural circuits that pertain to perception or movement decline in function. Various circuits decline at certain ages, and learning of relevant skills thereafter becomes hard (Thomas and Knowland 2009). For example, the playing of musical instruments, acrobatics, and gymnastics are easiest to learn in early childhood; and children who are "digital natives" show astounding dexterity in computer operation compared to adults. Another skill that may have sensitive periods is fluent and automatic reading (Abadzi 2012b).

The complex formation of skills implies that low-level difficulties may have higher-level implications. Slow performance of one component may drag down an entire chain. For example, someone learning to type at age 50 may send a few lines of email but may be unable to attain the automatized proficiency of a 20-year old.

Biological changes of puberty. Some little-understood mechanisms involved change learning ability. For example, the onset of puberty marks the end of the optimal period for learning language. A novel brain receptor emerges at puberty in the hippocampus, part of the brain that controls learning and memory. Before puberty, expression of this receptor is low and learning is optimal. However, at puberty, increases in this receptor reduce brain excitability and impair spatial learning. Interestingly, this learning deficit can be reversed by a stress steroid (called THP). Findings suggest that mild stress may reverse this decline in learning proficiency during the teenage years (Shen *et al*. 2014). Perhaps different strategies for learning and motivation may be helpful in middle school and later. These mechanisms, and potential remedies are being studied.

Age-related decline. Aging reduces the efficiency and the effectiveness of brain processes and renders many tasks more difficult with time. Lifespan changes in cerebral blood flow are partly responsible. Surprisingly, reaction times to demanding videogame responses start slowing down at age 24 (Thompson *et al*. 2014). Compared to young adults, older adults may take 1.5-2 times as long to perform certain tasks (Hale and Myerson 1995; Solokoff 1989). Visual working memory retains lower resolution pictures, so recall is impaired (Ko *et al*. 2014). Also older adults have been exposed to a lot of information over their lives, and sorting through the items to find responses may slow them down independently of neural deterioration (Ramskar *et al*. 2014). For example, processing speed decreases while working memory decreases also. This means there is less time to process and consolidate various information pieces.

Considerable research has taken place regarding the ages at which various skills peak (e.g. Hartshorne and Germine 2015). Cognitive-motor capacities are not stable across adulthood. There are significant age-related declines. Some abilities peak and begin to decline around age 10, others plateau in early adulthood, beginning to decline in subjects' 30s; and still others do not peak until subjects reach their 40s or later; and people show much variance in their age-related performance.

Specifically, cognitive skills peak at various ages (Germine *et al*. 2011). Cognitive processing speed peaks in the late teens, whereas learning and remembering names peaks in the early 20s. Working memory peaks at age 25-35, face recognition memory peaks in the late 30s. Social understanding peaks at ages 45-65, and vocabulary does not peak until age 65 or later.

Nevertheless, adults have compensating mechanisms. Older videogame players compensate by employing simpler strategies and using the game's interface more efficiently than younger players (Thompson *et al*. 2014). Different occupations make different demands on the brain, and the brain makes specialized neural networks in response to those demands. For example, if rapid perceptual discrimination is needed, the brain develops networks to support perceiving those patterns (Charness 2006:308). Adults can also be made to imitate younger people's learning strategies. For example, in learning to hit golf balls adults concentrate on movements, whereas children experiment in getting the ball to go where they want. Adults taught to focus on the aim may pick up skills much faster (Wulf 2007).

Thus with maturity, adults can learn some skills that would have required longer training for children. Psychosocial skills such as showing up on time and completing work are necessary in the formal and informal sectors, and adults with limited education may perform well (Hagan *et al*. 2014). Furthermore, when people understand the purpose of learning something, they pay attention and may recall the information more reliably (Perfetto *et al*. 1983). Interest and motivation to perform may facilitate performance of the task by leading to an increase in the time spent on with the task, watching examples, and practicing (Hidi 1990). However, other obstacles may arise in adulthood. Time, family obligations, and reduced plasticity must be considered.

The above adult education issues may also influence training of teachers and instructors. The findings suggest that it is feasible to train adults on issues involving higher-order cognition, such as the content of new curricula, but it may be harder to improve low-level skills. For example, a teacher who does mental math laboriously will surely improve with practice; but the timeframe, effort, number of tries needed are unknown. They may be more than an adult can invest in. And it is unclear whether the new level of performance will be sustained over time and whether the teacher will feel comfortable exercising this new skill along with other competing tasks that are lined up in a teacher's working memory. These are issues that are rarely considered and would benefit from targeted research.

The common confusion between explicit and implicit memory extends to preservice and inservice training of adult professionals. Many donors emphasize the need for communities of practice and reflection on teaching issues; but they practically never discuss teachers' needs for automaticity in the skills that they teach so that they have time in working memory to consider these high-level issues.

Practitioners such as nurses, teachers, and firefighters in many countries are required to have university degrees for certification and may be required to get master's degrees for promotion. Explicit knowledge is certainly needed in order to optimize decisions in these professions, but prioritizing it can result in considerable wastage. In fact, spending time in academic study may take time away from perfecting certain practices and becoming an expert. For example, Honduras instituted a Bachelor's degree for inservice teacher training; subsequently a study found ambivalent relations between training and student achievement. In fact, teachers' study toward a degree was negatively associated with students' achievement in some subjects (Honduras Secretaría de Educación 2002:70).

Since training issues of adults are poorly understood, governments and donors rarely plan for adult training that will be sustained in long-term memory. Sessions may be brief or merely consist of one-time lectures that leave little long-term recall. There is little time realistically available to practice skills with spaced repetition. And training activities are often done in groups that (as discussed earlier) have positive and negative aspects. Coworkers may give each other valuable information, but some may also leave the practice up to other group members.

Research on the practical aspects of training adults for implicit memory is extremely limited. Studies mainly consist of motor skills performance and military uses. Also research to roll back sensitive periods is in its infancy. Thus policymakers have limited help in understanding how to tailor training to adults more precisely in various circumstances. Without such information, the realism of the international lifelong learning agenda is questionable.

Perhaps 21st century skills require 21st century technology. There are prospects for optimizing training using brain plasticity to advance and recover skills (Merzenich *et al*. 2013). Likely means of speeding up performance consolidation includes fast-action videogames, transcranial stimulation, and certain drugs. Some technologies are already in use, but they cannot be generalized to international populations. And ethical issues about their use have not yet been resolved.

13. "Non-cognitive" skills, executive functions and personality traits

Knowing how to perform certain tasks is usually not a sufficient qualification for recruitment. Employees must also have "soft skills": energy, involvement, initiative, good interpersonal relations, presentability (Wang 2012:18). They must go to work on time, spend the working time productively, resist boredom and distractions, avoid procrastination, exercise self-control to manage impulses and show discipline (Steel 2007). They must also show social intelligence: negotiate, integrate effectively in teams, exercise critical thinking, and work towards company goals. There is much interest, therefore, in improving performance in "non-cognitive", psychosocial factors that influence job success, particularly among low-income students.

Studies have shown the desirability of such traits. In a British survey, about 35% of employers reported a skill shortage in recruitment, but of those, only 43% reported a lack of technical skills as the problem; 62% reported "poor attitude, motivation, or personality" (World Bank 2011). Similarly, Peruvian employers stated that social skills are the ones most wanted and hardest to get; the labor market places a high value on them (Blom and Saeki 2011). Such preferences were factor-analyzed into interpersonal skills, initiative, dependability, and lack of negative characteristics (Blom and Saeki 2011). The researchers recommended that schools somehow teach these skills.

However, knowledge about social interactions is also stored in the implicit memory system. We find ourselves carrying out transactions and obeying rules in various cultures when we are not sure what they are or why they are there. Yet we must all learn these implicit rules and perform satisfactorily in them in order to find or keep a job. As with other implicit skills, training procedures are challenging. (See Kautz *et al*. 2015 for a detailed review.)

Considerable research is going on about these skills and their antecedents. Executive functions are most easily shaped in early childhood (Diamond and Lee 2011), and students with the poorest executive function benefit the most from the intervention. As with other learning features, executive function has specificity. In adolescence, interventions to increase self-regulation and to redirect student beliefs have had promising effects, in some cases causing lasting improvements for children across multiple domains of development (Duckworth 2014; Yaeger 2014; Cohen 2014; Raver 2014).

There is some international evidence regarding effectiveness. Among poor households in Mumbai, psychosocial skills (self-esteem and efficacy) directly correlated with wages, and additional controls for cognitive outcomes had very little impact on wages (Krishnan and Krutikova 2012). The effect of the intervention on these psychosocial measures is between 0.75 and 0.90 of a standard deviation. That's an enormous increase in wages (between 10 and 20 percent). Also non-cognitive improvements persist and may become salient over time (Andrabi *et al*. 2009).

Psychologists refer to response frequencies of certain traits in terms of personality;[12] and certain personality traits are linked to better relations with employers (World Bank 2011). This observation led to an investigation of personality characteristics as a possible avenue for intervention. Specifically it attempted to identify the optimal phases and modalities for development of specific socio-emotional skills that employers seem to particularly value (Guerra *et al*. 2013).

This and other reviews highlighted the importance of variables such as openness to experience, conscientiousness, or perseverance (World Bank 2014b). In particular conscientiousness and agreeableness are important for success across many jobs, spanning across low to high levels of job complexity, training, and experience necessary to qualify for employment. These are often constituents of scales measuring integrity and customer service orientation. There are debates, however, about hiring people who are easy to get along with vs. hiring those who get the job done (Sakett and Walmsley 2014). Overall, implications of various personality traits are somewhat contradictory. These traits are not mutually exclusive, and performance may depend on circumstances.

Nevertheless, personality traits do not easily improve through training; they form complex interactions between biological variables (such as levels of neurotransmitters) and personal situations (see Abadzi *et al*. 2014 for a review). They are partly innate and hard to modify. Furthermore, these traits are not exactly

[12] The main personality variables often used in research have the acronym OCEAN: openness to experience, conscientiousness, extraversion, agreeableness, neuroticism (Borghaus *et al*. 2008).

"non-cognitive." They are related to intelligence and processing speed (DeYoung 2011). For example, openness to experience may be linked to working memory span and intelligence quotient (Kaufman 2013).[13] Relevant traits are intellectual engagement, intellectual creativity, mental quickness, intellectual competence, introspection, ingenuity, intellectual depth, and imagination. Therefore the flexibility that employers demand is partly a proxy for intelligence. Given personality complexities, employers particularly interested in such traits could hire for them rather than for skills (McIver *et al*. 2014).

It is important to prepare disadvantaged youth, in particular, for traits that employers consider important. *Prima facie*, training for personality variables and related skills would be difficult. In fact, some research has shown limited improvement in traits such as building relationships with others or giving support (McIver *et al*. 2014). Other research suggests that personality traits are more amenable to change earlier in a person's career (McIver *et al*. 2014). And it seems that emotional intelligence can be taught (Kahn 2013).

Also, some psychosocial skills may have a compensatory effect. For example, a conscientious person who executes more slowly may perform satisfactorily. Guilt-prone people may make valuable work partners because they are concerned about letting others down and may complete at least their fair share of the work (Wildermuth and Cohen 2014). One goal may be to lead employees through such improvements to an "autonomous extrinsic state", where they feel responsible for the work and carry it out on their own (Gagné and Deci 2005). By contrast, narcissism and inflated egos are reported among workers born in the 1980s in the United States, as well as an external locus of control and a reduced sense of personal responsibility (Twenge *et al*. 2008).

It is hard to acquire good manners without the opportunity to witness them and their effects. Programs have been tried in the United States and are complex, but could potentially be adapted. Vocational training programs may target these skills specifically. They may include exercises on how to ask for something nicely, thank people, acknowledge contributions, and practice other refined skills that signal productive and peaceful relations. These may include videos and practice on how to interview and the impressions people make in the first few seconds. People are more likely to carry out future intended actions if they plan them in detail (Kliegel *et al*. 2007; Gollwitzer and Sheeran 2006). Conscientiousness may be reinforced during school and through improvements in executive function. Mexican migrant workers to the United States showed with the passage of years, acquisition of socio-affective skills through informal observations, actions, and reinforcement (Hagan *et al*. 2014). Therefore an uneducated person can learn and automatize "non-cognitive" skills, such as meeting work targets and being polite to customers.

Mentorship appears to be effective. In the United States, graduates who had good relations at work often reported that a teacher had shown interest in them

[13] Support for the role of intelligence in openness was offered through a 16 week problem-solving program (Jackson *et al*. 2012). Older adults completed a 16-week program in inductive reasoning training supplemented by weekly crossword and Sudoku puzzles. Participants in the intervention condition increased in the trait of openness compared to a waitlist control group. The results suggest that if employees are able to learn and retain more, they may be more open to doing so at work.

(Friedman 2014). However, in a U.S. poll only 22% of college graduates surveyed said they had such a mentor and 29% had an internship where they applied what they were learning. So less than a third were exposed to the things that mattered most (Friedman 2014; Lumina/Gallup 2014).

Overall, avenues for improvement may exist. But the programs implemented thus far have been complex, expensive, and best suited for low-income students in high-income countries. More thinking is needed on efficient methods for lower-resource environments.

14. The “4Cs”: Critical thinking, creativity, communication and collaboration

Studies and blogs sometimes mention that children and youth should acquire the "4Cs" in order to be employable in the 21st century. These are critical thinking, communication, collaboration and creativity (e.g. Kolk 2011; Akyeampong 2014). Ideas on how to acquire them are often vague, but one proposed option is to teach these skills directly.

In principle, it is possible to give to students activities that will make them think more creatively while collaborating, examine information critically, and communicate their findings expressively. Good schools engage in such activities. But these four skills depend on complex reasoning as well as multiple low-level skills that must first be automatized. They result from multiple decisions over time, given prior knowledge, problems to solve, rewards, and punishments.

According to some studies, employers expect thinking skills in order to meet goals and solve corporate problems (e.g. Blom and Saeki 2011; World Bank 2011). To what extent do these benefit employers? The research on these complex skills is extensive, but relevant information is given below.

Critical thinking is a way of deciding whether a claim is true, partially true, or false. It includes observation, interpretation, analysis, inference, evaluation, explanation, and metacognition (Reynolds 2011; Schouteden et al. 2014). It avoids common cognitive biases. These include seeing one side of the issue, discounting evidence that disconfirms preconceptions, reasoning from emotions, failure to get support from evidence. Critical thinkers may also show novelty and self-direction; they do not simply remember a solution, but they devise an algorithm (Willingham 2007).

Critical thinkers must make decisions on content and rules of logic. Information therefore must be processed within the limits of working memory; people must be able to hold various concepts into working memory, link them, and make good decisions on the basis of the data. Therefore critical thinking about a topic becomes possible mainly after retrieval of the relevant knowledge has been automatized.

Programs to train critical thinking have been devised in higher-income countries, but they have had ambivalent results (Reynolds 2011). Proficiency in the relevant component skills is often not taken into account as a prerequisite. Furthermore, learning specificity may also mean that trainees can learn to think critically about some situations but may not do so under all circumstances.

Creativity and innovation have received much attention by donor agencies. According to a World Bank document, “traditional mindsets stifle creativity and risk-taking.” Preparation for complex skills would require divergent thinking and imagining several responses to a problem rather than a single right response (Banerji *et al*. 2010:19-20).

As with critical thinking, the ability to be creative in a domain requires detailed and rapidly available knowledge about it. Some highly creative people also tend to daydream often. Creative solutions tend to arise when people are relaxed but have an urgent problem to solve (see Abadzi *et al*. 2014 for a research review). Training for creativity produces results, but there are concerns that these may be specific to various domains rather than foster a general tendency for creativity.

Innovations are product of creative thinking. In the research, these are defined in terms of distance from ordinary solutions (Abadzi *et al*. 2014). However, the many educational references to innovation lack criteria for rarity of solutions.[14] They also lack references to effectiveness of innovations over solutions that be perceived as more “traditional.” This vagueness can have serious policy consequences, because it may encourage governments and training institutions to invest in methods that are eye-catching, without effectiveness data.

Communication depends on complex use of spoken and written language, and as such, it is linked to educational levels. Education would be particularly important when employers want good use of multiple languages, such as English or French in addition to the national languages. To attain the desired standards, schools must offer practice of basic skills to automaticity.

An important component of communication skills consists of writing. A large vocabulary is needed, along with correct usage of grammar. The ability to compose facts and arguments that do not tax the readers’ working memory is important. As with other skills, it results from much practice and feedback on composition. However, the extent to which lower-income schools engage in this practice is unclear. Teachers with limited education and large classes may not take the time to give such assignments frequently and to provide feedback sufficient for improvement. Research on this topic has been limited, but students’ ability to express themselves orally and in writing may depend heavily on their socioeconomic status.

Collaboration and teamwork are important for workers. As discussed earlier, cognition has situated aspects, and information from peers may speed up knowledge acquisition. However, group dynamics may result in censorship and reduce creative ideas. In some respects it may be best if people think of ideas on their own and anonymously interact with the group (e.g. through software; see Paulus and Brown 2003). Overall, every worker must be able to act independently.

[14] See for example, http://www.euronews.com/2015/10/30/innovative-education-ideas-reap-rewards-and-awards-in-kenya-and-ghana/

Constant operation in teams may create dependence on others that employers may not appreciate.

The research suggests that advice to focus education on the "4Cs" may lead to modest outcomes. By contrast, governments should be advised to focus first on the three "Rs" (reading, writing, and arithmetic) that are indispensable for the complex cognitive tasks suggested in the "4Cs."

Furthermore, hiring large numbers of employees who possess the "4Cs" may prove challenging to employers. Critical thinkers may engage in unwelcome scrutiny of company ethics, finances, or regulations and even whistleblowing. Highly creative people may require special management. Such people are more likely to be viewed as aloof, arrogant, competitive, hostile, independent, introverted, lacking in warmth, nonconformist, norm doubting, unconscientious, and unfriendly (Batey and Furham 2006). They may also behave dishonestly (Gino and Ariely 2012). Highly creative women may be particularly disliked (Brownlee 2013). And students who spend school time communicating in free-floating teams and thinking critically about general issues, they may find the experience enjoyable but fail to learn the component skills that lead to learning and employment outcomes (Clark 1989).

Complex skills require the ability to extrapolate essential gist through the analysis and synthesis of information, prediction of potential outcomes, abstraction of ideas, and integration of relationships with world knowledge (Gamino *et al*. 2014). In principle, it is possible to train students specifically for this function. A U.S. study of disadvantaged junior high school students showed that cognitive training increased gist reasoning by 25% and fact-recall abilities. Seventh and eighth grade girls and eighth grade boys showed significant increases in gist reasoning after training regardless of socioeconomic status. By contrast, a control group did not show these improvements (Gamino *et al*. 2014). The program is complex and depends on highly educated teachers, but in principle remediation is possible.

To explore in greater detail the probability of obtaining skilled people available for labor markets, two issues are discussed below: the role of status and of gender in vocational choices.

15. Skills and job status

Skills typically convey social status; occupational prestige is a sociological field with considerable research (e.g. North and Hart 1949). Mere ability to execute chains of actions is no guarantee that people will be willing to carry them out. Research suggests that some jobs are undesirable for upwardly mobile people.

Farming, animal husbandry, fishing, fishing boat steering, bricklaying, plumbing, knitting, or weaving, leathermaking often confer low status. Income is low, and the perception of smell and dirt involved in some of them are strong deterrents. So agricultural schools beg for students and close while families may make big sacrifices in favor of tertiary education. For example, rural Chinese families may spend their life savings in coaching classes to help children pass university entrance examinations in hopes of avoiding the construction industry jobs (Larmerdec 2014);

and in some countries school leavers may refuse to work in menial jobs and join the ranks of the unemployed.

Occupational prestige has important consequences that are not always positive. As mentioned earlier, some motor and perceptual skills are most easily learned in childhood (Thomas and Knowland 2009). In forming life cycle skills, early inputs strongly affect the productivity of later inputs (Heckman 2006). Children who go to school for long hours may miss out on practicing traditional skills like shepherding or collecting olives. If they have a need later on to take them up, they may be less efficient. Child labor is certainly undesirable; but children have traditionally learned household chores at a very early age. And the acquisition age of certain skills, including perceptual expertise and executive function, needs to be understood better.

One case in point is agriculture. In many parts of the world, the older generation has not passed on the relevant skills to the next one. Industrialized methods need fewer people to cultivate the fields, so the young have been getting better jobs. But agriculture has fed humans for millennia, and expertise in executing its tasks may still have utility.

For example, the economic crisis that hit Greece in 2010 left many educated people unemployed, whose families still owned fields and orchards. Yet, for many it has been inconceivable to “return to the land” and earn a living through it (Savvidis 2015). Status issues are one obstacle, but lack of fluency in the procedures is another. In many villages, the people who can teach them are elderly, aged 70 or above.

In principle, educated people can study videos of the activities, understand principles, adapt movements, and potentially find innovative solutions and gain efficiencies. But are these advantages enough to overcome a lack of implicit memory from childhood about agricultural and animal husbandry tasks? Are there perhaps sensitive periods involved in perceptual or motor circuits related to traditional occupations? Do children learn implicitly environmental signs combined with motions that as adults they will have difficulty executing? These questions have never been researched. But whether due to training difficulties or due to occupational prestige, Greece continued to import Albanian and Bulgarian agricultural workers while deep in economic recession.

One policy implication is the importance of keeping up skills passed on from the earlier generations. Some constitute significant national assets. Many countries have small programs of artisan training which use the guidance of older people. But overall, little thinking has taken place among governments and donor agencies. Certainly, research on the age-related productivity involved in various traditional skills is needed.

16. Skills and gender issues

After two decades of advocacy and studies on girls’ education, one would expect that women would enter and competently carry out most traditionally male professions, particularly those not requiring inordinate physical strength. However, in many countries the permissible range of professions for women has barely budged. The differentiation is striking at the low-income occupations that require manual work.

Consider an example: a nonprofit organization operating in a poor African country proudly shows in a video its vocational training achievements. Groups of men are learning to repair bicycles. Groups of women are learning to make flower decorations. The earnings potential and utility of these two professions differ starkly. Why does this gender difference exist after decades of emphasis on women's education?

Skills have hefty gender issues that have been poorly researched. One issue is social status for occupations, so women may be particularly unwilling to continue, for example, their foremothers' agricultural work. But another is the traditional division of labor. Evolutionary research suggests that division of labor across genders has had survival value (Buss 1989). In the higher-income countries of the 21st century this value may be diminished, but tendencies to carry out gendered work persist. And they have profound consequences for women's labor market participation.

The differences are hard to pin down. Gender effects in skills performance are small overall, and the performance distributions between genders overlap. But some obstacles exist. Testosterone confers an advantage of spatial orientation to male animals, including rats and fish (Spitzer *et al*. 2011). Spatial skills strongly predict achievement and attainment in science, technology, engineering, and mathematics fields (e.g. Wai et al. 2009). Math performance in large samples typically shows women trailing men in math (e.g. Stoet and Geary 2013), but in a number of countries, girls seem to perform in mathematics as well as boys. Nevertheless, studies suggest a more limited understanding of physics (McKagan and Sayre 2013). One result may be slight delays in decisions based on variables such as mental mathematics (Bailey *et al*. 2012). Working memory limitations may compound these effects.

Social issues also divert women from traditionally male professions. Well-paid jobs such as truck driving may clash with the feminine image that women must maintain. Male groups may exclude women or harass them. The multiple and complex labor problems limit earnings and opportunities. The gender gap is often very large among young people who have dropped out of the education system after completing only primary school. Men of limited education may rise to technically skilled professions, but similarly educated women are typically limited to manual service jobs.

A study carried out in the United States showed differing relationships between skills, interest, and incomes by gender (Lee *et al*. 2015). Linkages between male-typed interests and skills were bidirectional, that both male-typed interests and skills in adolescence predicted working in male-typed occupations in young adulthood; skills, but not interests, predicted income. By contrast, female-typed interests predicted female-typed skills, but not the reverse; adolescent female-typed skills (but not interests) predicted working in female-typed occupations in young adulthood, and there were no links between female-typed interests or skills and income. There are important vocational implications, given skills choices by adolescent women. Adolescent girls may avoid certain subjects, and early choices may later limit their employability.

The studies on women's labor participation, particularly in low-income countries or traditional societies, document some of the results (e.g. UNESCO 2012:17). In Jordan, over 80% of young women with only primary education were not actively seeking employment, compared with 20% of young men (Groh *et al*. 2013). Fewer women than men try to find work, often because of the unequal division of domestic work and discrimination in recruitment practices. Perceptions of competence and decisions about whether women are worthy of mentorship are often important. The wage gap is widest for those with low levels of literacy and numeracy. Yet education can make a big difference to women's earnings. In Pakistan, women with a high level of literacy earned 95% more than women with no literacy skills, whereas the differential was only 33% among men (UNESCO 2012).

One side effect that can limit female employment is a lack of practice. Women may be less likely to practice and improve skills that they have learned. For example, unemployed female engineers may soon forget what they knew. And women with degrees in humanities may exit the labor force and miss out on the procedural knowledge involved in female professions. To understand these issues, neurocognitive research is needed that has not yet been conducted.

17. Vocational-technical education and the instruction of skills

The technological evolution has complexified many jobs (Aedo *et al*. 2014). For example, farmers earlier cultivated the land with a plow, but now the required skills involve tractor driving, connections of various appendages, and repair of farm machines. Basic skills are required for these occupations, and they cannot be efficiently taught through social interaction and informal means. Therefore, relatively formal and systematic training is increasingly necessary.

So, how to teach in order to optimize formation of stable implicit memory in certain skills? Which institutions and which program types will offer skills training of sufficient length and variety to overcome specificity and automatize skills chains? The general parameters of skills learning have training implications for technical and vocational education and training (TVET), particularly in lower-income countries.

In many respects, the outlook is not encouraging. The teaching methods that are feasible in lower-income countries may be insufficient for proficiency.

Most educational settings focus on teaching conceptual, explicit knowledge (Sun *et al*. 2007). Classroom-based instruction can most easily and cheaply teach explicit knowledge. Students can listen, take notes, read, contemplate the information, analyze, synthesize, practice test-taking, and study for homework (Speelman 2014). Practicing chains of actions to automaticity and learning procedures is certainly attempted through laboratories. But the frequency and intensity are uncertain, particularly when the performance goals vis-a-vis the labor market are fuzzy. Training for procedural memory may be too expensive and time-consuming for many institutions. Besides equipment and materials, it requires highly trained staff who are themselves proficient at the skills they must impart.

Vocational instructors of high-income countries may empirically discover effective means for training students in implicit memory (see, for example, Lucas *et al*. 2012). But in lower-income countries many secondary, vocational, and tertiary institutions lack the resources. Instructional time may be limited, and textbook shortages mean that class time is spent copying with little opportunity for comprehension or practice (Abadzi 2007). Trainees may not achieve the desired levels of automaticity or understand the principles that can create learning transfer. For example, medical and dental schools aspire to train practitioners, but practice opportunities and supervision may be insufficient. The result may be unskilled and dangerous physicians. Similarly, engineers may pass examinations on theoretical content but may lack opportunities to convert content into procedures.

Students of the various institutions also may lack the prerequisite skills for study. They may go to vocational-technical schools because they cannot handle the massive semantic memory tasks they must do in academic education. But in these institutions, they may again be forced to do the same. Basic literacy and numeracy are needed, that must still be automatized; and when resources are limited, explicit knowledge will predominate. For example, if there is a computer shortage, students may have to learn computer repair and programming from lectures, notes, and books rather than hands-on practice.

As mentioned earlier, instructor qualifications often fall victim to the same fallacies about procedural knowledge. Usually technical or university degrees are required for teaching in formal institutions. However, the people who have these degrees may themselves have learned the content from books and may not have practiced sufficiently. For example, an instructor certified to teach automotive repair may have learned about cars from books and done few repairs. By contrast, an expert repairman may be barely literate and therefore unqualified to teach in vocational institutions. Surely instructors with limited procedural experience would not prepare students to fulfill employers' expectations. Some of the employers' discontent, therefore, may be due to teachers' limitations in procedural knowledge. Students may be able to recite the parts and functions of air conditioning equipment, for example, but be unable to diagnose malfunctions.

Misunderstandings over the above issues have resulted in large-scale strategies and plans to institute competency-based approaches. Many African countries adopted these strategies and developed curricula accordingly. However, competencies imply prior automatization of some skills that students often do not possess. Predictably, these curricula have not helped students (Sané 2013).

Donors often expect that illiterate or barely literate youth will acquire complex skills through short training schedules (World Bank 2010 and 2013b). Some agencies formulate programs for "accelerated human resource development." Vocational courses of a few weeks or months are often favored because of low expenses, but also because adult students may be unable to devote 2-3 years to training. However, the likelihood of acquiring sustainable skills may decrease when courses are short or one-time events. Memory consolidation may require longer practice and longer periods, particularly for adults. Short courses may have a better chance at providing skills when training alternates between class and practical experiences, such as internships. But research is needed to inform donors and governments of optimal training periods as well as realistic opportunities for skills retention.

Given the above inefficiencies, several reviews of TVET, particularly in lower-income countries, have produced outcomes with typically ambiguous or mixed results (Adams 2008; Soler-Hampejsek et al. 2013). Tertiary non-university institutions and some college careers show returns that are not very attractive, and even negative when direct costs are factored in. There is also considerable variation in the returns to training programs. The returns to firm-based training programs, and increasingly those offered by universities, are higher than those of the main technical skills formation institutions. This suggests that the latter are not equipping trainees with valued skills (World Bank 2011). This is not surprising. And modest evaluations have resulted in policies to move away from vocational institutions, particularly public ones that have limited resources and staff.

Unfortunately, the issues are poorly understood. Failure of institutions to teach job-relevant skills is attributed to regulatory failure or deficiencies related to accreditation. Students' ability to acquire the skills through the timeframe and methods offered practically never gets discussed.

Thus the question remains on how to optimize the interface between the semantic memory of classroom instruction and the implicit memory of practice. An optimal combination from the perspective of memory may prove very expensive in financial and human terms.[15] The realistic solution has been to teach semantic memory in hopes that students will later apply it to procedures. However, semantic memory is subject to forgetting, and by the time it is needed, it may not be available in memory. It can be recovered in principle, through formal or informal review. But these issues have not been dealt with in policy dialogue or in research.

Apprenticeships

Trainees must first "plug" in order later to "plug and play." One way to acquire procedural knowledge is through apprenticeships; students may practice what they learn and obtain feedback as well as mentoring. The effects are widely recognized, and many efforts have been undertaken to establish organized and sustainable schemes of "dual" systems of traditional apprenticeship where learners alternate between the classroom (for theoretical learning) and the workshops of the master artisans (for practical skills training).

[15] Some private schools in the United States strive to teach through implicit memory; for example students may wander in a garden during class, guided by a hand-held computer. In principle, implicit memory is durable and can be instantly recalled in the right circumstances, so as workers, students may know what to do for some topics (by contrast, the same information learned from books is more prone to forgetting). But implicit memory is not easily testable, long-term effects are uncertain, and such methods are most applicable to knowledgeable and wealthy students. Efforts are also being made to use implicit memory for language instruction to adults, in expectations of lower efforts. However, the research is not clear, and ultimate efficiency is unknown.

However, this strategy takes effort, political will, and business collaboration. Germany runs the oldest and most well-known apprenticeship system, college-age students can train for 356 different jobs—from oven builder to optician (UNESCO 2012). Other countries have had less involvement. In the United States, apprenticeships are few and rarely available (Siemens 2014). Formal apprenticeships are much more difficult to implement in poorer countries, but can work under appropriate conditions. Egypt adapted the German model to its own context, with business associations playing a key role in providing training places. A third of graduates from the program were able to find work immediately and about 40% continued in further education (UNESCO 2012:24).

Apprenticeships can be of particular benefit to the disadvantaged, but apprenticeship programs can be discriminatory. In the United Kingdom, for example, only 32% of black and other ethnic minority youth enter apprenticeships, compared with 44% of young white people. Women are less likely to find apprenticeships, and those who do earn 21% less from these opportunities than men. Career counselling can help more disadvantaged young people find and stay in apprenticeships, or ease the transition to work as experience from Japan has shown.

One reason for the scarcity is that for many companies, apprenticeships and internships are hard to handle. An employee must spend time to teach trainees the various skill components, then supervise. And trainees are likely to work elsewhere, so many companies have insufficient incentives for spending time and money. Also they must have a number of employees, and in many low-income countries companies are small; and those that exist may instruct relatives or people with whom they have other social connections.

As discussed earlier, skills can be acquired in informal environments and informal apprenticeship training. In fact, the informal sector accounts for more than 80% of all skills training in some parts of Africa (ILO 2007). Informal sector training is more flexible than school-based TVET that imposes rigid admission criteria and age limitations on learners. However, it may not be closely tailored to learners' needs. Ultimately, it depends on individual personalities, so it has mixed results (Robb et al. 2014). Clearly performance standards ought to be better specified.

Some programs have created enhanced opportunities for students develop implicit memory while they are within the formal education system. One of them arose in response to employment difficulties of most general or engineering graduates in India due to limited experience. A program (Aspiring Minds by Medha NGO; mdsf.org) offers third-year college students on-campus Career Boot camps. They provide skill training and then assist students with identifying job opportunities, preparing for interviews and negotiating salaries. Skill training consists of (a) in-class training in areas such as business communication and teamwork, and (b) internships to impart industry-specific skill training. The organization has already assisted more than 1,000 students.

The concerns about vocational-technical strategies raise the obvious question of how well donor policies on skills have performed thus far. In early 2015 this was unclear. Donors focus on systemic issues and expect that training institutions will somehow teach the needed skills. There is little if any interest in instructional outcomes, so investments do not directly focus on students' skills. Nevertheless, the few projects found had modest outcomes.[16] For example, the World-Bank's Jordan Employer Driven Skills Development Project that closed in 2013 had moderately unsatisfactory outcomes. A 2011 project for Rwanda that had intended to teach complex skills explicitly, was restructured (World Bank 2013a). A 2001 skills development project in Armenia supported by UNICEF had modest outcomes and multiple issues (Ashton 2001), as did a Canadian project (Human Resources and Skills Development 2012). Clearly many confounding variables are involved, so a broader study is needed of outcomes in skills projects.

18. How wide is the skills gap? Scrutinizing various claims

It is safe to assume that a significant skills gap exists in many countries. But to close it, real information is needed about the staffing needs of various employers. The mismatch between employer demands and trainee profiles has been taken at face value and merits some scrutiny.

Surveys of firms have drawn up lists of desirable qualifications and features (e.g. Blom and Saeki 2011; World Bank 2011). Data are based on the statements of company representatives but it is unclear how much hiring power the respondents have. The size of the companies is rarely discussed. Labor market surveys may include biases about actual hiring decisions and salaries; for example, employers may want certain skills but only be willing to hire relatives or certain ethnicities. Surveys of employer desires should therefore be matched with hiring patterns.

There are good reasons for questioning the size of the skills gap. In many countries the fastest growing sectors of the economy have been low-skill jobs rather than those requiring university degrees. These include health care assistant and construction industry jobs, which often pay little and require low levels of qualification. Those who want professional-level positions may remain unemployed or only work part-time. In 2011 in Australia, 43% of young people in work were working part-time hours, the corresponding figures in the UK were 37% and in the Netherlands 66% ; In the United Kingdom, the Trades Union Congress showed in 2013 that since 2010, 77% of new job creation has been in low-paid industries. (Furlong 2015; ILO 2013). In the United States, healthcare support positions are projected to increase by 28% in 2012-2012, compared to 18% of mathematical and computer positions (18%; Bureau of Employment Statistics 2013).

Given the above data, the skills gap in the United States may be mostly a corporate fiction, based in part on self-interest and a misreading of government data (New York Times Editorial Board 2013). Corporate hiring has been limited. If a skills gap were really a problem, companies would lower expectations, offer higher salaries, and train workers. Instead, skills mismatches may refer to salary disagreements. Claims about poor education may result from a corporate strategy be to shift training costs to the government (Cappelli 2012).

[16] Retrieved from: www.worldbank.org/IEG

In countries where the skills gap really exists, specificity is crucial. It is important to gauge which skills employers truly need from the large menu of “21st century skills” and what precise work functions they fulfill. It is important to obtain data on how much employers of various sizes are willing to pay for them in training and in salaries. Furthermore one must question: What percentage of the employable population really has the desirable “cognitive” or “non-cognitive” skills? And in what timeframe are relevant skills reliably teachable to average people?

The willingness of some organizations to take employer surveys at face value raises again the question of cognitive biases. Perhaps professionals pay more attention to the kinds of jobs that they do and disregard statistics which show that these jobs are rare. The skills gap, therefore may be exaggerated.

Overall, there is a risk that governments and donor agencies are developing policies on the basis of employers’ profit strategies or memory illusions. It seems important, therefore, to obtain more realistic data and also to educate officials about the ubiquitous cognitive biases and how they can adversely affect government strategies.

How to promote complex skills acquisition? Policy and research implications

The skill formation concepts outlined in this review starkly differ from the concepts presented in various donor and government documents. The implications are many. Some points are mentioned below, but they barely scratch the surface.

All donors and governments want students to get more education. But the limited understanding of how people learn skills, coupled with middle-class bias, creates unrealistic expectations about how much people can retain from training, given what they know and how training is delivered.

Some agencies advise in favor of reverse-engineering complex skills, in expectations that students will increase their income by getting direct training in complex skills. However, the desirable skills depend on proficiency in the lower levels of a skills hierarchy. It may be impossible to learn composite skills without first automatizing their components. And this must be done at ages when subsequent units can be learned quickly and efficiently.

Other agencies expect that people with little education will acquire sustainable market skills through short courses that are useful to employers (World Bank 2010 and 2013b). Thus, programs are promoted for students of average or below-average performance with timeframes and budgets that are unrealistically low. Participants may be faced with tasks that are nearly impossible, given what they know when they enter a training course. Consequences are human but they are also financial. Potentially billions of dollars and years of student lives are placed at risk, if governments follow ineffective policy advice.

One important variable that must be considered are the *lower limits of the human information processing system*. Learning is a biological process that has physical limits. These have not been charted, and even their possibility has not been discussed. Empirical studies should establish the timeframe needed by people of various performance levels to attain desirable skills, but these do not exist. Thus, even rough estimates of skills acquisition as a function of instructional time are unavailable. But common sense makes it obvious that minimal instructional time may enable mainly the few most intelligent people to get trained. In fact it is worth considering whether the amount of time, financial resources, and teachers needed to impart complex skills to nearly all students in a country is feasible. And if adults past their peak rates of various skill acquisition levels are considered, the estimates may prove beyond practical consideration.

So rather than clamor for innovative ways of teaching, international agencies should advise governments to ensure efficient instruction of basic skills. This means detailed curricular attention to basic steps, at least in reading and mathematics (Speelman 2014). In addition, spatial skills and intuitive physics are needed. Instructional time use, textbooks for all, apprenticeships and internships, opportunities for adaptive imitation would help.

At this time decision-makers do not sufficiently understand “21st century skills,” so they cannot effectively modify them on a large scale. A “theory of change” is needed that explains how they develop and why they fail. Cognitive science provides a research-based theory of change. Skills are memory phenomena that can be explained through the ways the brain works. *Ultimately DNA dictates how people learn and forget, and genetics cannot be disregarded at will*. To educate and train segments of the population, learning curves can guide governments. They provide predictable trends that can help with time and budgeting to optimize performance.

However, the international education community seems to have little interest or appetite for cognitive science. The staff of various government and donor agencies have spent years thinking about skills from the perspectives of economics, training philosophies, and from personal schemes that appear real to them. People do not easily change their decision algorithms (Shtulman and Valcarcel 2012). Limited knowledge and cognitive biases create adverse conditions in imparting valid policy advice.

Thus a triple challenge arises: (a) disseminating sufficiently detailed information about memory functions, (b) dealing with staff bias convincingly, and (c) financing research to find out how to train low-income populations most efficiently.
It is unclear how this challenge will be dealt with. The outlook therefore, for training the poor to attain complex skills more effectively is not very optimistic.

To vocationalize education or to generalize it?

Secondary education policies merit reassessment, given the research body on skills acquisition. The issues, particularly for lower-income populations are multiple and contradictory.

The research may weigh into a decades-old debate: should secondary education be general or vocational? Governments have oscillated back and forth (Akyeampong 2014). As mentioned above, in general studies certain principles may be applicable, but students will have learned semantic content rather than procedures. By contrast in technical-vocational education, students may get more procedural practice, but fail to understand principles. The argument in favor of general education may in some way be related to executive function and "soft skills." Students who tolerated the dense instruction in higher cognitive functions may have the prerequisites for hiring. Students who were behavior problems may have gone to vocational institutions and associated more with similarly acting students. No research has been found that separated these two effects.

Additionally, the research raises questions regarding secondary education. This education stage still provides students mainly with declarative knowledge. In principle this could be useful for understanding certain principles used in the workplace, assuming that students learn the material and recall it when they arrive at the workplace. But there is a tradeoff. Lower income and rural students may miss out on opportunities to practice during their teenage years skills that have helped their ancestors subsist for centuries. As graduates, they may be unemployed. They may lack the social skills and political connections to get a job in the city or even the means to stay in the city and look for a job. Furthermore, low-income and rural students often have more limited knowledge. Thus, the policy of emphasizing secondary education for all may be sensible in terms of equity but short-sighted in terms of income generation.

The possibility should be considered that not all secondary school students can carry out complex skills within the instructional time offered in lower-income schools. Age, gender, but also intelligence may have an influence. It is important to channel failing secondary schools students into training programs that can optimize skills involving implicit memory and minimizing complex knowledge demands. However, as mentioned earlier, TVET does not necessarily provide efficient training.

One striking deficit in the research is the paucity of data to inform pedagogical advice and formulation of training programs at various levels. Even empirical data seem lacking in the various publications. The research about instructional time and duration of various training programs may be neglected because beliefs about the learning process seem self-evident. The time and materials needed to teach various programs and subjects require validation with average and below-average students. Attendance, dropout, and success rates should help determine the duration, distribution, and amount of practice necessary to develop stable skills for most learners.

Overall, 21st century skills are inspirational, and writers wax poetic about them. They reportedly constitute tools for working, preparing youth to live in multicultural, globally integrated societies, with "non-cognitive" skills. However, globalization has also had a perverse effect; globalized violence involving automatized chains of complex skills. Educated outlaws seem much more effective than the often illiterate criminals of earlier eras. Perhaps never before have so many young men received high levels of education coupled with a nonstop barrage of violent movies and TV. The ability to do this with apparently little effort serves to remind us how memory works. The only thing that cannot be adapted in a reasonable timeframe is the DNA code that gives rise to human memory.

Future steps and research needs

To bridge the skills gap, it is necessary to bridge the knowledge gap about skills first. In particular, the research about real-world applications of implicit memory is scant. It is limited to experiments with animals and military uses, rather than performance conditions similar to those faced by workers of the 21st century. Most important, it is fairly obscure and its broader implications are not understood.

The limited attention to the learning aspects of skills acquisition means that little or no research has been done to elucidate how to train students more efficiently. International organizations could finance and encourage such research. Some of the topics could involve:

– *Studies and data collection to use better the predictive power of the learning curves research* in order to specify realistic skills attainment targets for various populations.

– *New means to enhance the efficiency of skills training*, including means to enhance the incidence of apprenticeships and mentorships. In particular there is a need for research-based innovations to shorten the practice timeframe for automaticity.

– *Overcoming early deficits*. The advantage of training children early in certain skills is well known, but there is little research to understand how to overcome early deficits. Some measures of skills progression are needed across grades for average students from average backgrounds and low-income environments.

– *Experiments to determine approximation of graduates to the skills realistically expected* by selected employers; amount of time and resources for recruits to reach the performance level that employers realistically require. For example, what percentage of the realistically available jobseekers can comfortably attain various skills, given the time available, levels of teacher education, materials, and language competencies?

– *The learning and forgetting trends of complex skills*. The industrial training experiments of the 1950s and the studies estimating the likelihood of forgetting items in lists offer possibilities of estimating how much students are likely to remember given very limited instruction (e.g. Altmann and Schunn 2012). Similarly, timeframes, practice time, latencies, and resources needed for various types of skills to be automatized in realistic schools settings, particularly in low-income environments.

– *Studies to clarify the age, gender and social status effects*. These issues are politically sensitive, but ultimately they must be faced and improved. In particular, research is needed on the age-related productivity involved in various traditional skills.

– *Optimizing computer use*. Some skill components could be attained with careful use of computers. In particular, computerized instruction may offer possibilities to engage in implicit learning. However, some instructional programs that relied on computer use have not shown the expected effects (e.g., Sharma 2014, OECD 2015). The reasons are unclear but they may include distraction due to multitasking or a lower likelihood of remembering content (e.g., Aranha and Sholl-Franco 2013). It is important to understand how to make computer use more effective in formulating complex chains of skills.

In the past, the donor community has shown little interest in using cognitive science research for education strategies. Means must be found to increase adoption. At the very least, the skills gap can be mitigated by shining a light into the dark network of implicit memory.

Annex: Examples of learning-related assumptions reported in various documents

Statement	What the research suggests
Students do not need to know facts, they can look them up on the internet.	We cannot directly link to knowledge lying on the internet. We must already know a great deal and be able to retrieve it in milliseconds in order to look up facts and then use results.
Flexible learning strategies are needed: learning programs that could provide *"flexible schooling that is shorter, more practical, more focusing on learning, and further reaching than formal primary schools."*	Demands are contradictory; flexibility is desirable, but encoding and practice require time. Long-term consolidation is a biological process that must get the time it needs.
Employers have a message for teachers and principals in primary and secondary schools. Critical thinking, problem-solving and communication skills are not acquired though rote learning where the teacher lectures and pupils copy – still the reality in many schools. If the education system is to deliver the skills that employers want, the method of instruction will need to change (from a blog).	This appears to be a personal theory about memory operations, without research support. Critical thinking and communication are higher-order skills, aggregated from prior automatized knowledge. "Rote memorization" of certain essential items is necessary and is initial step towards that goal.
School systems should no longer organize curricula by discipline and give tests on content ("hard skills"). They should teach a new set of skills, combining basic, new, and soft skills. Students should work in groups so that they can easily integrate in teams at work.	Disregard of content shows disregard of automaticity needs, which are unconscious and not easily recalled in personal experience. Indiscriminate group work may compromise individual students' learning.
Skills are only of value when they are used – whether in the labour market or in other non-market settings, such as voluntary work, home production or even in leisure activities. Unused skills represent a waste of skills and of initial investment in those skills. As the demand for skills changes, unused skills can also become obsolete; and skills that are unused during inactivity are bound to atrophy over time (OECD 2013b:20).	It demonstrates a lack of awareness that skills are composed of automatized components which could be used in other actions. The unconscious nature of memory often results in beliefs that it is stable. Long-term retention depends on the amount of prior learning. Forgetting is usually caused by interference rather than decay
In 2015 the World Bank is to install "outernet" hardware in South Sudan across several cities, providing free information access to millions. The $15M Global Learning XPRIZE will bring literacy to millions of children worldwide.[17]	These statements assume that access to the information is self-evident and focus on technology details. However, beneficiaries must have complex skills and language knowledge to access and understand the information. Among the poor, these are often scarce.
Curriculum design in the 21st century must incorporate clear understandings of learning: definitions, sensitivity to cognitive development, social contexts of learning and metacognition. They include fundamental areas of knowledge (STEM learning, information literacy, concepts focused learning), competences (creativity and critical thinking) and attitudes (academic honesty, health and mindfulness, service learning; Acedo and Hughes 2014).	These qualities are all very desirable. But curricula must be designed to teach and consolidate the underlying skills first. At higher levels of education, policies must exist to ensure that the underlying skills chains have already been consolidated. Remediation should be planned for those students who lack automaticity in the prerequisite skills.
Occupations which require intensively manual skills, associated with many jobs in low-machine intensity farming but also with specific trades as	Complex operations require much prior explicit and implicit knowledge. This must be somehow taught within curricula and

[17] http://learning.xprize.org/about/guidelines

well as mass-manufacturing, give way to occupations requiring more cognitive skills. Such cognitive skills include verbal ability, working memory, numeracy, and problem solving abilities – teachers will need these intensively as well as computer operators (Aedo *et al.* 2013).	timeframes suitable for average and below-average students. They also require teachers with sufficient knowledge and automatized skills for these subjects. Such teachers may be scarce in the population.
Engineering education institutions should: (i) seek to improve the skill set of graduates; (ii) recognize the importance of Soft Skills, (iii) refocus the assessments, teaching-learning process, and curricula away from lower-order thinking skills, such as remembering and understanding, toward higher-order skills, such as analyzing and solving engineering problems, as well as creativity (Blom and Saeki 2011).	The need for automaticity in the lower-order thinking skills is discounted. Learners are expected to exhibit higher-order skills and skip the components. Without procedural knowledge, graduates can just talk about problems but not solve them. Soft skills are expected to be taught as an academic subject.
The more modern the economy and the more sophisticated the division of labor in production processes, the more important are also interpersonal skills which underlie behaviors such as teamwork, reliability, discipline, and work effort (Aedo *et al.* 2013).	All societies depend on collaboration, so it is an evolutionary trait. Interpersonal skills are necessary at all labor levels. The authors seem to express personal perceptions regarding older and modern economies.
Socio-emotional skills like the ability to persevere towards long-term goals entail a life-time earnings dividend in urban Peru comparable to that of cognitive ability (i.e., intelligence; (Blom and Saeki 2011). Workers who are more intellectually curious and open to experiences are more likely than others to report solving complex problems and learning new things at work. (World Bank 2014b).	Socioemotional skills are partly genetic and also linked to intelligence. Workers who exhibit these traits may be more intelligent. Education increases "crystallized" intelligence, but actions to improve these traits directly are probably not feasible at this time.
Make upper secondary education more accessible to the disadvantaged and improve its relevance to work; Upper secondary education must be in tune with the skills needs of the labour market. First, it has to strike a balance between technical and vocational and general subjects by providing flexibility in subject choices and links with the workplace (UNESCO 2012:31).	Vocationalization of secondary education may contradict some memory functions. Learning specificity and transfer difficulty raises doubts regarding the utility of vocational skills taught at this level. The most work-relevant content at this level may be automatized basic skills and "non-cognitive" work-related traits.
Three main types of skills that all young people need: *Foundation skills* include the literacy and numeracy skills necessary for getting work that can pay enough to meet daily needs. *Transferable skills* include the ability to solve problems, communicate ideas and information effectively, be creative, show leadership and conscientiousness, demonstrate entrepreneurial capabilities. *Technical and vocational skills:* Many jobs require specific technical know-how, from growing vegetables to using a sewing machine, laying bricks or using a computer (UNESCO 2012).	This typology seems to result from personal insights and has no reference to research. The statement ignores the progressiveness of skills from simpler components to more complex chunks. Also makes assumptions about transfer of learning. The technical skills definition shows confusion between explicit and implicit memory.

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