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How is Technology Changing Demand for Human Skills?

This chapter examines the concepts of complex communication and expert thinking, and discusses the importance of foundation skills in the workplace and in individuals' personal and civic lives. It also discusses how the labour market is evolving and raises the question: How well are national populations prepared for today's – and tomorrow's – jobs?

It is a characteristic of labour markets that technology can change the nature of work faster than people can change their skills. Innovation is central to market economies and it is impossible to imagine many of the new occupations that are likely to exist in a decade's time. But while we don't know everything about future occupations, we do know something about the skills these future occupations will require.

The largest technological force now shaping work is the computer. Computers are faster and less expensive than people in performing some workplace tasks, but much weaker than people in performing other tasks. It is important to remember that computers substitute for some work (issuing metro tickets, for instance), and complement other types of work (providing computerised images that assist in medical diagnoses). By characterising the kinds of work computers do well, we can begin to describe the work that will remain for people in the future, the skills that work requires and the way that computers can assist people in performing that work.

We can get a picture of what computers do by considering three workplace tasks:

- In railroad stations, the task of selling tickets to particular destinations, a moderately skilled task, is increasingly performed by self-service kiosks rather than by desk agents.
- In industrial seaports, the task of recording and tracking the movement of sealed cargo containers is increasingly done automatically using signals emitted from radio frequency identification (RFID) tags. The task used to be done by clerks who inspected containers visually.
- In a doctor's office, the doctor makes a diagnosis using a computer to access a patient's electronic medical records, which contain the patient's medical history, including procedures performed by other doctors. The doctor then uses a computerised search to look for potential treatments for the patient's condition. In the past, the doctor would have worked from paper medical records that might have omitted other doctors' procedures, and he would have searched for potential treatments in his reference books, some of which might have been out of date.

Why do we see this particular mix of outcomes? How do we explain the fact that computers *substituted* for human work in issuing tickets and tracking cargo containers while they *complemented* the doctor's diagnostic skills?

The answer begins with two ideas:

- All human work involves the cognitive processing of information. The financial analyst who reads numbers in a spreadsheet, the farmer who looks to the sky for signs of rain, the chef who tastes a sauce, the carpenter who feels his hammer as it hits a nail – all of these men and women are processing information to decide what to do next or to update their picture of the world.
- We can think of a properly running computer programme as a series of rules that specify an action for each contingency. Computers execute rules. Some of the rules involve arithmetic (6 x 9 = 54). Other rules involve logical conditions (If [AGE > 35] Go to Statement 13).

When these two ideas are combined with common sense, they say that a computer can substitute for a human in processing information when two conditions are present:

- The information to be processed can be represented in a form that is suitable for use by a computer.
- The processing itself can be expressed in a series of rules.

The first condition is common sense. The information-processing rules in the second condition can be either deductive or inductive. Deductive rules arise from the logical structure of the process. For example, in the case of the railroad ticket kiosk, some deductive rules might be:

- "If the destination is Kyoto, the ticket price is JPY 5000."
- "Read the person's credit card number."
- "Send the person's credit card number to the issuing bank to authorise the charge."

Information-processing based on deductive rules is often described as rules-based logic.

Inductive rules – involving a more complicated situation – typically refer to equations based on regressions, neural nets and other statistical models, where the parameters of the model have been estimated on "training samples" of historical cases. The equations with their estimated parameters are then used to process new cases. Information-processing based on inductive rules is usually described as pattern recognition. It is this pattern recognition that permits a radio receiver to identify the signal from the RFID tag on the cargo container. Other pattern-recognition software is used to recognise words in voice-recognition devices and to recognise potential fraud in credit card-purchasing data.

The third example is different. A computer can *complement* the doctor's diagnostic skills by providing a full patient history and searching for potential treatments that the physician might not otherwise find. At the same time, a computer cannot *substitute* for diagnostic skills, *per se*.

More precisely, the doctor performs two tasks that cannot be easily computerised. The first involves eliciting information from the patient. As any doctor will testify, this is not a simple process. It involves listening to the patient's words. It also means reading the patient's body language – the tone of voice, the avoidance of eye contact or the broken-off sentence that indicates the patient is holding something back. The doctor must be particularly alert for the famous "last minute" of an appointment, when the patient, on his way out the door, looks over his shoulder and says "By the way, my wife says I should tell you about this pain I have in my stomach."

Many other jobs today involve similarly complicated human interaction. We can call these interactions "complex communication".

The doctor's other non-computerised task involves constructing a diagnosis from multiple sources of information: what the patient has told him, the patient's medical history, his knowledge of the medical literature, his experience with past cases, and so on. This task has not been computerised because it cannot be expressed in a set of step-by-step rules (see also Schultz, 1964). Many other jobs today also involve solving problems that lack rules-based solutions. We can call this style of problem-solving "expert thinking".

Computerised information-processing tends to use rules-based logic and pattern recognition that can sometimes replace the need for human input in solving known or anticipated problems. However, solving new or unanticipated problems, or solving problems that lack rules-based solutions and require non-linear, case-based reasoning demand expert-thinking skills. In technology-rich environments, where information is abundant and circumstances can change rapidly, the ability to establish a common understanding of information is highly valuable and requires complex communication skills to elicit information and draw connections.

A technology-rich workplace still requires solid foundational skills, including numeracy, literacy and reading ability, which are all tested by PISA. But such workplaces also require advanced problem-solving and advanced communication skills. The educational and training implications of complex communication and expert thinking cannot be reduced to rules, making them relatively difficult to both teach and assess.

But what exactly are complex communication and expert thinking skills? And what opportunities and challenges do they raise for education and training programmes?

Complex communication

A dozen years ago, at the height of the dot.com mania, experts predicted that the Internet would eliminate millions of jobs in management, teaching and sales – jobs that involved communicating information. Networked computers, people assumed, could communicate the information at much lower cost than traditional modes of person-to-person communication.

In practice, these jobs are as important as they ever were. The reason why lies in a basic cognitive principle: information is inherently ambiguous, and we give information meaning by imposing a context. Without a shared context, there is no guarantee that the recipient of information will interpret it as the author intended. A good example of this principle comes from what may still be the shortest correspondence on record.

The correspondence began with a telegraph consisting of a single character "?"and the reply was a telegraph consisting only of "!".[1]

We don't send many telegraphs these days, but what would you think if you received a letter consisting only of "?". If you had a child away at school you might assume the letter was about money. If you hadn't called your mother recently, you might assume the letter was a pointed reminder. Read by itself – taken out of context – the question mark tells you little.

In fact, this particular question mark was written by Victor Hugo. In 1862, Hugo finished *Les Misérables*. Exhausted, he dropped the manuscript off with the publisher and left for vacation. Though Hugo wanted to relax, he also wanted to know how the book was selling and so he telegraphed "?" to his publisher. The book was a smash hit and so the publisher could telegraph back "!".

Hugo and his publisher each knew what was on the other's mind – they shared a context.

This was the point the dot.com forecasts missed: the work of managers, teachers, sales people and others is not to convey information *per se* but to establish a context in order to convey a *particular interpretation* of information. When a salesperson says you look perfect in lime-green pants, you cannot know, based on the verbal information alone, whether the salesperson is being honest. The other things the salesperson does – reading your body language, quickly correcting misunderstandings, smiling at appropriate times – are designed to establish a context in which you assume you are hearing the truth.

In the same way, writing down formulas on a blackboard is a small part of a calculus teacher's job. The teacher must use examples and back-and-forth conversation to create a context in which students can understand what the formulas mean. And asking "What seems to be the problem?" is only the start of the doctor's work to discover and diagnose the patient's symptoms.

Mastering complex communication – the ability to establish a common understanding of information – is a highly valuable skill, particularly in technology-rich environments where information is abundant and circumstances can change rapidly.

Expert thinking

When a problem can't be solved by rules, it is necessary to look for other ways of solving the dilemma – what can be called expert thinking. Expert thinking is a collection of specific solution methods that vary according to the problem at hand. One frequently used method is what cognitive scientists call case-based reasoning. The method is illustrated by an example from automobile repair.

A customer brings in a recently purchased Fiat® – a new model – with a non-functioning power seat. A technician uses a computerised diagnostic tool to search for problems. We noted earlier that any software programme, including the software in the diagnostic tool, is a set of rules specifying actions for various contingencies. But automotive engineers who write the software can only write rules for the contingencies they have anticipated: a faulty switch, a break in the wire connecting the switch to the seat motor, a faulty seat motor, and so on.

In other words, the diagnostic tool can solve "known" problems, but solving "new" problems remains something for humans to do. In a new car, the many new electronic components can interact in ways engineers have not foreseen. If the seat problem is caused by one of these unanticipated interactions, the factory-programmed rules will detect no error and the technician must solve the problem another way.

In case-based reasoning, the mechanic begins with a kind of pattern recognition in which he recognises points of similarity between the current problem and other problems he has solved in the past. He uses his previous solutions as a starting point for constructing a new solution – for example, looking for failure points that he had seen in analogous problems but that the diagnostic tool did not cover. It is likely that the doctor, diagnosing a patient, uses case-based reasoning in a similar way to start constructing a diagnosis, comparing points of similarity between this patient and other patients he had treated in the past.

What stands out about this problem is that there is no straightforward solution path. That is no accident. Problems with straightforward solution paths are increasingly solved by computers; meanwhile complex problems like this will comprise an increasing share of human work. It is that fact that makes expert thinking important.

The educational and training implications of advanced skills

It is useful to step away from the argument for a moment to see the educational and training implications of these advanced skills. Every teacher knows that rules-based skills are relatively easy both to teach and to test. The problem, as we have seen, is that skills that can be codified in rules can also be performed by a computer. By their nature, complex communication and expert thinking cannot be reduced to rules and so they are relatively difficult to both teach and assess.

With respect to expert thinking, begin with the fact that everyone agrees that children need "problem-solving" skills. In practice, however, problem-solving skills have often meant focusing only on rules-based solutions, like the rules of algebra. The rules of algebra are very important, but applying algebraic rules is just the second step of a two step problem-solving process. The first step – the step computers can't do – involves examining the messy set of facts in a real-world problem to determine which set of algebraic rules to apply – the expert thinking.

Today, the labour market values a mechanical engineer's ability to formulate a problem as a particular mathematical model. Once the model is formulated, a computer – not the engineer – will apply rules to calculate the actual solution. How does the engineer choose the correct mathematical model? As with the earlier cases of the auto mechanic and the doctor, she likely relies on analogies with problems she has solved in the past. It follows that her education must include numerous real-world problems to give her experience on which to draw – a relatively time-intensive process.[2]

Similarly, the skill of complex communication cannot be learned simply by reading the right book. It requires extensive practice and teacher-student interaction. Similarly, because formulating good communication is not a rules-based process, assessments are not easily reduced to multiple-choice, machine-graded tests.

Advanced skills and foundational skills

Common sense says that advanced skills like expert thinking and complex communication must be preceded by a strong foundation in literacy, numeracy and reading. Nonetheless, it is useful to review several mechanisms through which computerisation makes foundational skills particularly important.

There is, first, today's rapid pace of change. An example of the relationship between literacy and the rate of change occurred some years ago in a plant assembling electronic controls for missiles. The plant was located in the southern US and much of the assembly was performed by men and women who had worked as agricultural labourers. Many were illiterate and so they could not read assembly diagrams but they learned to assemble specific components by watching their neighbours. This method of learning broke down because engineers were constantly changing components to address performance problems. The result was a stream of change orders from the engineering division to the assembly line. The illiterate workers were lost because they could not read change orders. Today, as computers accelerate workplace change, being able to understand descriptions of new procedures becomes essential.[3]

A second mechanism linking computerisation and foundational skills involves the way computers have transformed concrete processes into numerical abstractions. Some years ago, the Ford Motor Company experienced this problem in the course of changing from mechanical carburettors to computer-controlled fuel injection. Repairing the computerised modules required an ability to read manuals and mentally connect digitised read-outs on diagnostic tools with the (now invisible) processes they represent. A number of mechanics, who were quite skilled repairing physical carburettors, could not make this transition.

More generally, as computers have lowered the cost of calculation, numerical tools and models now permeate many jobs, and holding one of those jobs requires becoming a mathematics consumer. A clothing store manager uses a quantitative model to forecast dress demand. A truck dispatcher uses a mathematical algorithm to design delivery routes. A bakery worker monitors production using digital readouts rather than the smell or feel of the bread. Employees of all kinds are expected to use web-based tools to help manage their retirement plans. Each of these tasks involves some aspect of numeracy. In most cases, a computerised tool does the actual calculation, but using the model without understanding the mathematics leaves one vulnerable to potentially serious misjudgements.

Numeracy, literacy and reading skills go well beyond what might be called "basic skills". Being able to multiply and divide will always be important, but they are not sufficient to deal with the abstraction of a computerised fuel-injection module. Similarly, a typical definition of "basic reading skills" is not sufficient to absorb the pages or web views of a repair manual including searching for the parts of the manual that apply to the case at hand.

The need for foundation skills applies beyond the workplace to personal and civic life. Consider the issue of food safety. Most products that are routinely purchased in shops and supermarkets undergo several stages before reaching the shelves: production, processing and distribution. Consumers get information about the safety and nutritional value of food products through labels. Interpreting food labels requires more than the "basic" reading and mathematics skills: citizens also need to have some general understanding of food production, the effect and nature of each ingredient, the rules governing labelling, the latest information on food safety, the impact of nutritional components on certain medical conditions, etc.

Box 1.1 **Foundation skills for the future**

As computers accelerate workplace change, being able to understand descriptions of new procedures becomes an ever-more frequent task. A second mechanism linking computerisation and foundational skills involves the way computers have transformed concrete processes into numerical abstractions. As computers have lowered the cost of calculation, numerical tools and models now permeate many jobs – holding one of those jobs requires mathematics skills. While a computerised tool may do the actual calculation, using the model without understanding the mathematics leaves one vulnerable to potentially serious misjudgements.

Note that the numeracy and literacy skills described in these examples go well beyond what might be called "basic skills". Being able to multiply and divide will always be important, but they are not sufficient to deal with the abstraction of many computer-generated analyses. Similarly, a typical definition of "basic reading skills" is not sufficient to absorb the pages or web views of a repair manual, including searching for the parts of the manual that apply to the case at hand.

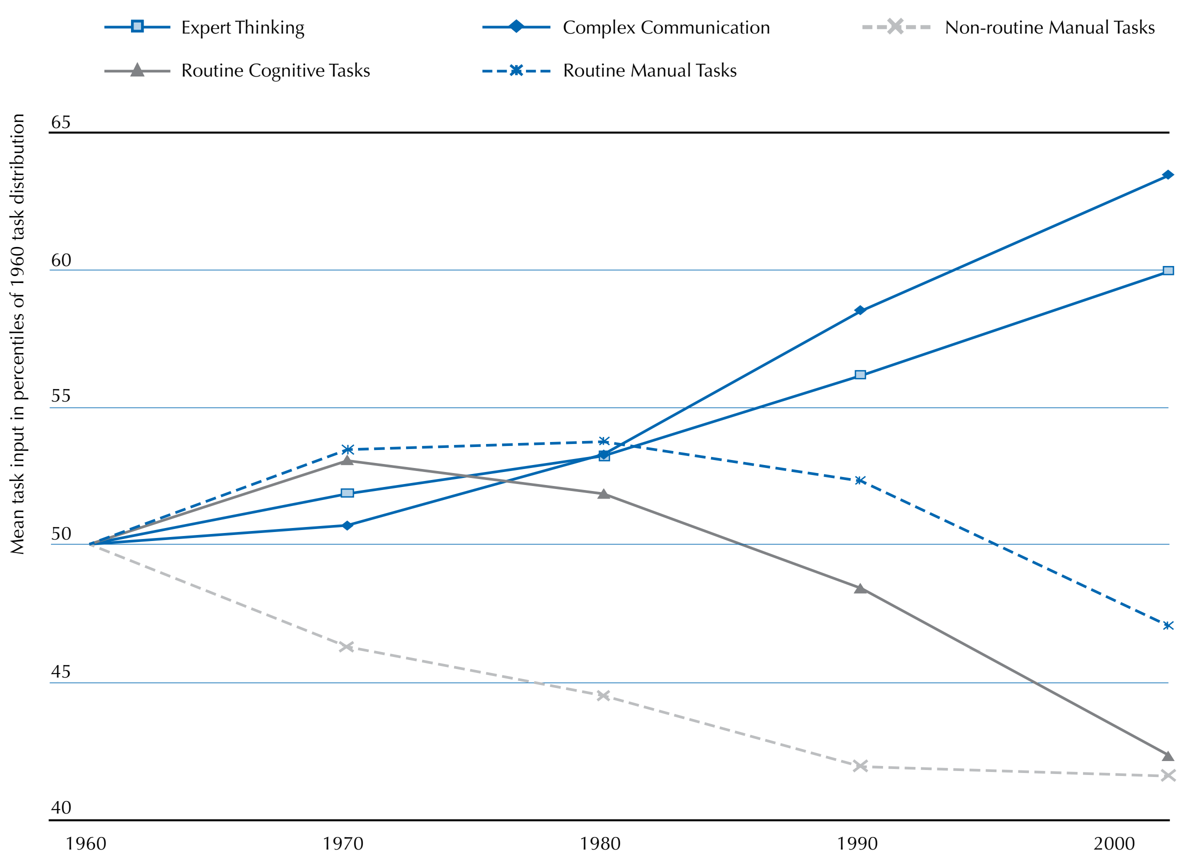
Complex communication and expert thinking are only two of the skills used in the economy but they are growing in importance. To see this, it is useful to classify all labour-force tasks into five broad categories:[4]

- Tasks requiring expert thinking: Solving problems for which there are no rule-based solutions. Examples include constructing a diagnosis of a patient's illness, repairing an automobile when the problem not addressed by diagnostic tools, and so on. While computers cannot substitute for humans in these tasks, computers can complement human skills by making information more readily available.

- Tasks requiring complex communication: Interacting with humans to acquire information, to explain it, or to persuade others of its implications for action. Examples include a manager motivating the people whose work she supervises, a sales person gauging a customer's reaction to a piece of clothing, a biology teacher explaining how cells divide, an engineer describing why a new design for a DVD player is an advance over previous designs.
- Routine cognitive tasks. Mental tasks that are well described by deductive or inductive rules. Examples include maintaining expense reports, filing new information provided by insurance customers, and evaluating applications for mortgages. Because these tasks can be accomplished by following a set of rules, they are prime candidates for computerisation.
- Routine manual tasks. Physical tasks that can be well described using deductive or inductive rules. Examples include installing windshields on new vehicles in automobile assembly plants, and counting and packaging pills into containers in pharmaceutical firms. Since these tasks can be defined in terms of a set of precise, repetitive movements, they are also candidates for computerisation.

■ Figure 1.1 ■

Trends in routine and non-routine task input in US occupations: 1960 to 2002



Source: Based on Autor, Levy and Murnane (2003), updated to 2002 by David Autor.

- Non-routine manual tasks: Physical tasks that cannot be well described as following a set of "if-then-do" rules because they require optical recognition and fine muscle control that have proven extremely difficult to programme computers to carry out. Examples include driving a truck, cleaning a building, and setting gems in engagement rings. Computers do not complement human effort in carrying out such tasks. As a result, computerisation should have little effect on the percentage of the workforce engaged in these tasks.

Figure 1.1 displays the evolution of each of these task categories in the US economy since 1960. Tasks requiring expert thinking and complex communication have grown substantially over time, while routine tasks – particularly routine cognitive tasks that are easily computerised – are declining sharply.

The task trends in Figure 1.1 correspond to a "hollowing out" of the US job structure, with the largest job losses coming among clerks, assembly-line workers, low-level accountants, customer service representatives – jobs in the lower middle of the earnings distribution that require rules-based processing of information and rules-based repetitive physical motions.[5] By contrast, jobs requiring expert thinking and complex communication – jobs with relatively higher wages – are growing at rapid rates.[6] As computers are increasingly absorbed into the labour market, these trends will almost certainly continue. Similar shifts are taking place in many industrial and developing economies, including Japan (Ikenaga, 2009).

This discussion reflects the evolution of the demand side of the labour market. A corresponding question applies to the labour market's supply side: How well are national populations prepared to meet the current job market evolution? Foundation skills are themselves important, but their application is evolving. In today's society, effective literacy often involves the ability to understand language to follow web-based instructions, assess the accuracy of information and so on. Is everyone able to effectively access, retrieve and interpret web-based content and apply information that is acquired through digital technologies to solve problems?

Technology can change the nature of work faster than people can change their skills. The problem is compounded because a nation's educational system can grow out of touch with job-market trends and effective policies to develop expert thinking and complex communication skills. PISA and the OECD series *Strong Performers, Successful Reformers* can help close this gap by describing a range of learning outcomes, policies, practices and other factors that can help inform evidence-based decision making by governments and education stakeholders. Policy analysis from several high-performing and rapidly reforming education systems will help to guide governments as they consider how best to prepare their young people for the unpredictable needs of the future labour market.

Notes

1. This example is adapted from Tor Norrestradners, *The User Illusion: Cutting Consciousness Down to Size*, Viking Penguins, 1998. The example has appeared in *The Guiness Book of Records* as the shortest correspondence.
2. Alan Lesgold argues that computer simulations can be useful in teaching subjects like electronics repair because the simulations can generate unusual problems faster than the the student would encounter them on the job. See Alan Lesgold and Martin Naherow, *Tools to Assist Learning by Doing*, working paper, Learning and Research Development Center, University of Pittsburgh, August 29, 2005.
3. See also, Theodor Schultz, *Transforming Traditional Agriculture*, Yale University Press, 1964.
4. This categorisation was initially developed by Autor, Levy and Murnane, op.cit.
5. Because repetitive physical motions can be expressed in rules, they are candidates for being performed by robots. In developed countries, their rules-based nature also makes the tasks candidates for being sent offshore to lower wage countries. See Levy and Murnane (2005) for further discussion.
6. Actual trends are likely sharper than those shown in Figure 1.1. Figure 1.1 is based on occupational shifts in the economy from 1959-99. Due to data limitations, the task content of each occupation is assumed to be constant at its 1978 level. This limitation obscures the task shifts that have occurred *within* occupations – for example, the way in which the development of the automatic teller machine has sharply reduced the amount of time a bank teller spends on cashing checks and accepting deposits and has increased the time spent on more complicated transactions.

References and further reading

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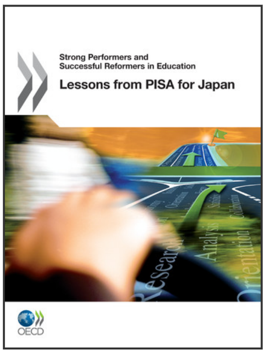

From:
Lessons from PISA for Japan

Access the complete publication at:
https://doi.org/10.1787/9789264118539-en

Please cite this chapter as:

OECD (2012), “How is Technology Changing Demand for Human Skills?”, in *Lessons from PISA for Japan*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264118539-4-en