Learning about learning: a cybernetic model of skill acquisition

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Abstract

Purpose – The purpose of this paper is to explain some phenomena observed in the acquisition of motor skills: the loss of conscious access to knowledge of the structure of a skill and the awareness that an error has been made prior to the receipt of knowledge of results. Although there are rich descriptive accounts of skill acquisition in the literature, there are no satisfactory explanatory models of the cognitive processes involved. The paper provides such a model.

Design/methodology/approach – In the 1970s, the first author implemented a computer program model of the cognitive processes involved in learning and skill acquisition, based on a series of empirical investigations. Recently, with assistance from the second author, the model has been reviewed, updated and re-implemented. The paper sets this work in the broader context of a theory of learning and teaching, conversation theory.

Findings – The model provides a constructivist account of skill acquisition and associated phenomena. The model provides theoretical foundations for conversation theory.

Practical implications – The model adds to the understanding of motor skill acquisition and to the understanding of processes of learning and teaching in general.

Originality/value – The model and its interpretation are an original contribution to the skills acquisition literature.

Keywords Second-order cybernetics, Learning, Cognitive model, Conversation theory, Skill acquisition

Introduction

Second-order cybernetics is concerned with explaining the observer to herself (von Foerster, 2003). In this respect, studies of how humans learn are second-order pursuits[1]. Not only do such studies add to the body of scientific knowledge in psychology, reflexively they inform the investigator (and the reader who studies her findings) about his or her own cognitive processes. This reflexion can be used in powerful ways to improve on one’s ability: to learn, to teach, to teach others how to learn and to teach others how to teach.

In the 1970s, the first author implemented a computer program model of the cognitive processes involved in learning and skill acquisition based on a series of empirical investigations (Scott, 1976) of the acquisition of a keyboard skill, the skill of “touch typing”[2]. Recently, with assistance from the second author, the model (referred to here as the “Typist” model) has been reviewed, updated and re-implemented (Bansal, 2010)[3]. The paper begins with an overview of learning theory that introduces “conversation theory” as a general theory of learning and teaching. It then looks in more detail at skill acquisition, with specific reference to the Typist model. This is
followed by a discussion of how the Typist model, when generalised, provides theoretical foundations for conversation theory. Finally, there is a brief overview of the significance of conversation theory, not only as a theory of learning and teaching but also as a contribution to our understanding of consciousness and as conceptual bridge between individual and social psychology.

**An overview of human learning**

Humans, like all other biological organisms, are dynamical, organisationally closed, self-organising systems, surviving – and evolving – in world that can be hostile as well as welcoming and safe. Such systems survive by adapting to their worlds and by actively becoming “informed” of how their worlds work. “Learning”, as biological adaptation, happens incidentally in the context of the pursuit of current “need-satisfying” goals[4]. Learning is going on all the time. One cannot not learn. In humans, learning finds its perhaps highest expression. Our “need to learn” is so strong, we experience boredom and actively seek out novel environments. We readily acquire habits, construct mental models and solve problems. We consciously set ourselves goals. We reflect, conceptualise and converse. We come together to learn and to teach. When we learn, we are said to acquire “knowledge”. There are many ways of characterising forms of knowledge. Here, we will make use, of the distinction between “knowing why” (theoretical, conceptual knowledge) and “knowing how” (practical, performance knowledge).

“Learning” implies that new cognitive structures are acquired, if only as a consequence of adaptation. Constructivist theories of learning emphasise that, in addition, some cognitive structures and processes actively guide these constructive activities. Learners have intentions: they form plans and adopt particular learning strategies. Learners can learn to learn; cognition can pull itself up by its own boot straps. Kolb (1984), using ideas from Kurt Lewin and Jean Piaget, provides a simple frequently cited model of the processes involved in constructivist learning (see Figure 1). Kolb proposes that learning is a cyclic activity with four stages. These are: Concrete Experience, Reflection on that Experience, Abstract Conceptualisation (the derivation of general rules or theory construction) and Active Experimentation (the construction of ways of modifying the next occurrence of the experience).

Rescher (1973, 1977), also building on ideas taken from Piaget, has constructed a more detailed model than that of Kolb, in which two cycles of activity are distinguished: one corresponding to the acquisition and justification of “why”

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**Figure 1.**
Learning as a cyclic activity (after Kolb)
knowledge, the other corresponding to the acquisition and consolidation of “how” knowledge (see Figure 2). In the “why” cycle, new conceptual knowledge is integrated with existing conceptual knowledge to form a coherent whole. In the “how” cycle, new “methods” (procedures, operations) are constructed, tried out and subject to pragmatic correction.

The late Gordon Pask developed conversation theory, based on concepts taken from cybernetics. Throughout several decades, he actively applied his ideas in education and in the development of man-machine teaching systems (Pask, 1975b, 1976). Pask’s basic model is shown in Figure 3. Pask refers to this model as the “skeleton of a conversation”. It shows a “snapshot” view of two participants (learner and teacher) in conversation about a topic.

Notice how it distinguishes verbal interaction (questions and answers) from behavioural interaction via a shared modelling facility or “micro-world” or other “learning context” such as a laboratory or a classroom. The horizontal connections represent the verbal exchanges, conceived by Pask, not as direct transfer of information[5], but as “provocations” that are designed help the participants construct knowledge and “come to know”. Pask argues that all such exchanges have, as a minimum, two logical levels. In the figure these are shown as the two levels: “how” and “why”. As in Rescher’s model, the “how” level is concerned with how to “do” a topic: how to recognise it, construct it, maintain it and so on within the given learning context; the “why” level is concerned with explaining or justifying what a topic means in terms of other topics. The modelling facility allows the teacher to instantiate the topic by giving non-verbal demonstrations. Typically, such demonstrations are accompanied by verbal commentary about “how” and “why”. In turn the learner may use the modelling facility to solve problems and carry out tasks set. He or she may also provide verbal commentary about “how” and “why”. These distinctions allow Pask to give a formal definition of what it means to understand a
topic. For Pask, understanding a topic means that the learner can “teach back” the topic by providing both non-verbal demonstrations and verbal explanations of “how” and “why”.

Underlying assumptions of conversation theory include the following. The brain/body system is a dynamic self-organising, “variety-eating”, adaptive and habituating system, subject to boredom and fatigue. As Pask (1968) puts it, “Man is a system that needs to learn”, thus the problem of motivation is not “that we learn” it is rather what is learned and why. The basic mechanisms that support learning and adaptation are the various forms of feedback that guide the evolution of new forms of behavior: attentional systems subject to sensory-motor feedback (including proprioception and kinaesthesia) and algedonic (pain, pleasure) feedback. For humans, learning is also about the intentional construction of symbolic representations, subject to constraints of logical coherence, acquired through the medium of dialogic, conversational interaction and the inner dialogic processes of strategic and tactical attention directing[6].

In conversation, narrative forms are constructed and exchanged (Scott, 1999; Bruner, 1996). What is memorable is that which can be “taught back” (Pask and Scott, 1972, 1973). Habitual forms of behaving and thinking become non-conscious and automatic (proceduralised). The Typist model gives a detailed account of proceduralisation. In conversation theory, remembering is understood as a dynamic process of reconstruction that is always contextualised and social (minimally, with no other person present, a learner remembers with herself). Pask argues that the distinctions required to characterise the cognition of an isolated psyche are the same as those made by the external observer of a conversation (cf. Ryle, 1971). In the “outer conversations” that constitute social institutions, the participants agree and disagree and negotiate shared descriptions, explanations and justifications. In her “inner conversation”, a person explains and justifies herself to herself.

Pask notes that conversations may have many logical levels above a basic “why” level: levels at which conceptual justifications are themselves justified. Indeed, reflexively, the conversation itself may be the topic of conversation. Harri-Augstein and Thomas (1991) make these notions central in their work on “self-organised learning”,

\[\text{Figure 3.} \quad \text{The “skeleton” of a conversation}\]
where the emphasis is on helping students “learn how to learn”. In brief, they propose that a “learning conversation” has three main components: conversation about a topic, as in the basic Pask model, conversation about the processes of learning (e.g. discussing study skills and reflecting on experiences as a learner), conversation about purposes, the “goals of learning”, where the emphasis is on encouraging personal autonomy and accepting responsibility for one’s own learning (Figure 4).

We will now consider the Typist model of skill acquisition, following which we return to consider conversation theory as a general theory of human learning and consciousness and introduce some of Pask’s formal theoretical terminology: “concept”, “memory”, “mechanical individual” and “psychological individual”.

Skill acquisition
The term “skill” has a broader connotation than just perceptual-motor skills. It can also fruitfully be applied to the skills of cognition, metacognition, affect management and other aspects of self-organisation and self-steering. Indeed, living itself can be considered as the continual deployment and acquisition of skills. The stages in acquiring new skills are described in Scott (1976) as:

(1) the problem solving involved in building up a conscious representation of the structure of skill;
(2) the acquisition of subskills;
(3) the integration of subskills; and
(4) practice of skill leading to proceduralisation.

The study of the acquisition of motor skills has developed in several ways in recent years. The chief driver has been the increased interest in sports coaching and in physical therapy for those with disabilities (For a recent survey, see Davids et al., 2008).

Figure 4. A cybernetic model of skill acquisition
These developments are largely based on the pioneering work of Gentile (1972). Gentile provides a comprehensive taxonomy of different kinds of motor skill that takes into account the context in which the skill is performed and the degree of gross bodily movement that is entailed. Gentile makes a distinction between explicit and implicit learning. By explicit learning, Gentile refers to those aspects of the skill which are consciously selected and monitored during the acquisition process. By implicit learning, Gentile is referring to those aspects of skill acquisition which are carried on unconsciously as natural adaptations of the body. This distinction maps well onto the distinction in the Typist model between the conscious intentions of the learner as she guides and monitors her movements and the non-conscious adaptations of the brain/body system that are modelled as emergent, evolutionary processes.

The Typist model simulates the behaviour of a novice typist who is learning to press the correct key in response to single letter stimuli. The stimuli are presented at regular intervals [7]. Starting from the home keys, the learner must select the correct finger and move it in the correct direction. The learner is provided with cueing information showing the location of the key on the keyboard layout. She also receives a "knowledge of results" signal, indicating success or failure.

Key features of the model are:

1. The learner is modelled as a complex goal-directed adaptive system that is dynamically self-organising. The learner’s goal is to solve the problem of how to touch type proficiently.

2. Achievement of goals set is subject to a free energy economy simulated as available processing time or “effort”. A certain amount of effort is made available when a new problem is posed. The learner has to decide how best to “spend” that effort [8].

3. Learning is conceived of as a constructive evolutionary process in which, guided by knowledge of results with respect to a specified goal, problem-solving “operators” are selected from a population of possible responses.

4. Complex operators may be constructed from simple operators. Simple operators designate “which finger” and “which move” as separate operations. A complex operator designates “which finger with which move” as a single combined operation. The driver for doing so is simulated by the rule that a complex operator consumes less processing time than the equivalent set of simple operators.

5. If effort is available, knowledge of the structure of the skill and the knowledge of the keyboard layout of the keyboard may be used by “logical operators” to infer and construct new knowledge and new response operators.

6. The model simulates concurrency of processing, where the outcomes of the application of a particular operator may have implications for the outcomes of the application of others. The interaction of operators applied concurrently is simulated by a serial sequence of executions of the operators that exhausts the set of possible interactions. This means that some operators will be applied more than once for any given stimulus presentation.

The model provides an explanatory account of two empirically observed phenomena [9]:

1. Skilled practitioners lose access to a conscious knowledge of the skill structure; and
skilled practitioners are frequently aware, prior to the receipt of feedback about the consequences of their actions, that an error has been made.

What is being simulated is the novice typist’s construction and elaboration of a redundant representation of the keyboard. Specific mechanisms are concerned with how the internal representation is maintained and how it evolves. The general idea is that when a problem is correctly solved, those property descriptions that were assumed to be true of the problem situation (when the solution was inferred) are henceforth retained as descriptions that may be used in the future, perhaps in the context of other problems. Further, when a solution is executed (in typing, when a key is pressed), the problem solver may check, internally, to see if what he did does in fact bring about the solution he was aiming for. This is done by inferring from the knowledge of what was done (which finger, which move) what property values should be true and checking this against the known description. This latter mechanism is also a way to build knowledge of the keyboard. Given an external knowledge of results signal that says a solution was correct, the inferred description may be used to overwrite or modify or enlarge the description currently available. Proficient performance is characterised by the state of affairs where “which finger with which move” operators are immediately available and applied. With proficient performance, the redundant description ceases to be consciously accessible. This is simulated in the model by the redundant description no longer being used to construct new operators. However, the redundant description continues to serve as a non-conscious internal template or description of the desired goal that confirms or disconfirms what was done. A disconfirmation in the model simulates the situation where the proficient typist becomes aware of making an error: his/her daydream is interrupted and he/she is called upon to attend consciously to the task at hand. The theoretical justification for the form of the simulation is that the cognition of the typist is seen as a unitary organisation in which particular processes go on concurrently, autonomously and unconsciously so when they do not conflict. When there is conflict there is uncertainty; the learner becomes aware that something requires her attention. The uncertainty is reduced when the learner decides how to resolve the conflict.

The Typist model can be generalised for domains other than touch typing as follows.

In the model, operators are created and evolve that bring about finger movements and key pressing. In general, there are cognitive operators or processes that recognise, recall, bring about or maintain a relation in a (given) universe of interpretation. A useful general name for such processes is “concepts”. Also in the model there are operators (processes) that create and maintain the processes that bring about finger movement and key pressing. In general there are cognitive operators that recognise, recall, bring about or maintain concepts, “concepts of concepts”. A useful general name for such processes is “memories”. Recursively, one may have “concepts of concepts of concepts”. In the model, the overall process of acquiring and performing the skill has a cyclic form (see Figure 5).
More prosaically, knowing leads to doing which leads to further knowing and further doing. The process is a whole that reproduces itself in the context of the domain of touch typing.

In general, there are self-reproducing, self-referential systems of concepts and memories that evolve as adaptation and learning take place. In conversation theory such unitary systems are referred to as Psychological Individuals (P Individuals). The processors (such as brain/body systems and their augmentations) that may embody P Individuals are referred to as Mechanical Individuals (M Individuals) (Pask et al., 1973). Conversation theory had its beginnings in studies of skill learning; its scope was much enlarged by studies of the learning of academic subject matter (Pask and Scott, 1972, 1973). Scott (1993) provides an historical account of the development of conversation theory. Scott (2009) provides a summary of conversation theory’s key concepts.

It is impossible in a short paper to say all that could be said about the significance of the Typist model and its relation to conversation theory. Pask himself cites the model as exemplifying the evolutionary dynamics of human learning (Pask, 1975a, b). As noted earlier, the concept of what is a skill can be generalised to include all aspects of human behaviour and experience. One may live one’s life as a more or less skilled performance. Confucius, for example, emphasised the continuous cultivation of inner virtues. There are legions of self-help books that advise on how to live life happily and successfully. It is important to appreciate that a P Individual has evolved as part of human ontogeny. Pask takes from Vygotsky the concept of the inner dialogue that comes into existence as a child becomes a person. As Vygotsky (1962) notes, the inner dialogue becomes truncated as private discourse. As the Typist model makes clear, all aspects of cognition may become proceduralised. Thus, the private discourse, incorporating descriptions of the world, may become proceduralised as routines that guide behaviour.

With expert performance, one may become so absorbed that awareness of self disappears. von Foerster (2003) has proposed that, “I am the relation between observation of self and observation of the world”. If one ceases to observe self, “I” disappears[11]. The Typist model also makes clear that awareness may return when there is conflict or uncertainty. Following early work by Tolman (op. cit.), there is now a large body of work concerning the effect of stress on skilled performance[12]. With stress, skilled non-conscious performance is interrupted and one may find oneself regressing to the use of simpler procedures that were employed when the skill was acquired. For example, one may resort to finger counting when one’s mental arithmetic skills fade. When typing, one may resort to use of the “qwertyuiop” mnemonic to recall key positions[13].

The Typist model exemplifies the evolutionary mechanisms of brain/body dynamics (the M Individual) that bring forth the meaningful experiences of a P Individual. In turn, the goal-directed intentions of a P Individual constrain what may be brought forth. Conversation theory can be regarded as the most sophisticated theory of “mind/body” interaction that has yet been formulated. The M Individual grasps a tool, such as a walking stick. For the P Individual, the stick becomes an extension of its embodiment. When one touches something with a stick, one’s awareness is at the point of contact. When one drives a vehicle, one’s awareness makes the vehicle an extension of the body.

We hope we have given some idea of how comprehensive and unifying conversation theory is as a theory of human learning and conceptualisation. Conversation theory can also be seen as a major contribution to our understanding of consciousness and
awareness. Unlike theories derived from the writings of Sigmund Freud, it does not posit a separate domain of “the unconscious”. It asserts that conceptualisation is an ongoing, self-reproducing evolutionary process and that the “variety eating”, uncertainty-attending-to processes are those of which we become aware and which, as when one wakes from a dream, may become the focus of directed thought, as the P Individual sets and pursues goals. Pask, in his later writings, refers to directed thought as being orthogonal to conceptualisation (Pask, 1996). Directed thought is intended. Conceptualisation happens, albeit constrained and influenced by goals that have been set. The basic dynamic of conceptualisation is that distinctions between concepts may be voided (generalisation – dogs and cats are members of a larger class, keys “a” and “s” are both home keys) and new concepts may be generated from old ones (refinement – collies are distinguished from corgis, “a” and “s” use different fingers). Pask (1996) uses the metaphor of forces of attraction and repulsion to describe these dynamics: like concepts repel; unlike concepts attract. Ideally, a new concept is checked for how it coheres logically with other concepts and for how the pragmatic outcomes of its application conform or not to expectations (as shown in Figure 2). Unfortunately, we humans do not always carry out these checks.

Conversation theory thus provides a cybernetic explanation of the dynamics that William James’ (1890) describes as “the stream of consciousness”. Compared to conversation theory, other accounts of consciousness, although fleshed out by the many interesting findings in contemporary neuroscience, are conceptually impoverished and confused. Dehaene (2014) is a very recent example. His mappings of brain activity that accompanies subjective experiences show the (to be expected) concurrency of processes. However, he reifies “consciousness” as some sort of essence that has evolved to cope with this concurrency, instead of, as Pask does, recognising that awareness is a characteristic of all living organisms and that to be “conscious” (L. consciere, to know together) is to dialogically know with oneself or with another.

We accept the biological basis of the brain/body system being a complex adaptive whole (an M Individual). To that we have added the concept of an embodied cognitive system: an evolving, self-directing, self-reproducing Paskian P Individual. The external observer distinguishes an M Individual as an “it”. A P Individual is self-distinguishing. An observer distinguishes a P Individual when she engages with it as a “psychosocial unity”, a “thou” or “you”[14]. The term “psychosocial” alludes to the fact that, as elucidated by Vygotsky (op. cit.) and others, the “self” is constituted as a social process and consciousness, as distinct from undifferentiated awareness, has the form of an “internal” conversation. The M/P individual distinction allows Pask to deal directly with the social. For Pask, a P Individual is a conversation and, vice versa, a conversation is a P Individual. It is important to note that M and P individuals need not be in one-to-one correspondence. A single M Individual may embody several P Individuals as participants in the internal conversation. A single P Individual (a “we”) may be embodied by several M Individuals in an external conversation. In a stroke, as it were, Pask has unified individual and social psychologies[15].

Concluding comments
The Typist model explains key aspects of human cognition: how consciously constructed knowledge becomes proceduralised, how conflict in concurrently executed process may engender the conscious awareness of error and uncertainty. As noted in the introduction, our explanations are necessarily second order: they explain the observer to herself. As constructors of the model and narrators of the theory that gives
it significance, we are aware that we have been engaged in learning and the acquisition and performance of skills. Suitably generalised, our theory provides an account of its own genesis. One's intention to solve a problem and one's understandings of relevant principles serve as constraints to which evolving concepts must fit. The construction of a satisfactory new concept may happen within a few milliseconds or may require deep thought and gestation over a period of days, weeks or a lifetime.

Notes

1. All human psychology is second order in this sense. As well as to learn about others, a psychologist studies her discipline in order to learn about herself.

2. Touch typing is a secretarial skill where the operator copies a (possibly handwritten) text without looking at the keyboard.

3. The Typist model is part of a suite of models of increasing complexity, which are described in detail in a recent paper (Scott and Bansal, 2013). In that paper, the Typist model is referred to as the “Full Typist” model.

4. In work that predates the influence of cybernetics upon psychology, Edward Tolman, in his “cognitivist behaviourism”, refers to the acquisition of cognitive structures. He calls these “expectations”. More mainstream behaviourists, such as Clark Hull, referred to the acquisition of “habits” (see Tolman, 1948).

5. Since living organisms are organisationally closed systems, it is not possible to directly transfer “information”, as one might input data into a computer. Organisms select (capture) and interpret perturbations from the environment as being meaningful or not.

6. Pask frequently emphasised his indebtedness to Vygotsky (1962) for the concept of the “inner dialogue” (see e.g. Pask, 1996).

7. Keyboard skills, such as touch typing, are members of a larger class of skills that Pask refers to as “transformation skills”. These are skills in which, when presented with a stimulus configuration of some sort, the skilled practitioner must transform it into an appropriate set of responses. All tool-using skills are members of this class.

8. Pask and Mallen (1969) use a similar resource allocation economy in a digital simulation of the acquisition of a key pressing transformation skill. Their simulation is a direct ancestor of the Typist model described here and, in more detail, in Scott and Bansal (2013). For a recent commentary about this early work see Mallen (2013).

9. A number of relevant empirical studies are described in Scott (1976). The Typist model and associated theorising (and, indeed, conversation theory as a whole) are complemented by a large body of empirical studies that gave rise to them and which have been inspired by them (see e.g. Pask and Scott, 1969; Pask, 1975a, b).

10. The model is available online with an interface that: permits the setting of relevant parameters and provides a visual display of the model's workings as it learns. For access, please contact the first author.

11. Glanville makes a similar distinction in his key assertion that self-observation and observation of the world are orthogonal, non-intersecting processes. See Glanville, 2002, 2014).


13. For a wide ranging discussion of the distinction between “fast” non-conscious thinking and “slow” conscious thinking (see Kahneman, 2011).
14. Deacon (2012) develops the concept of a self-referential cognitive system that is somewhat analogous to a P Individual. However, he does not emphasise the psycho-social aspect of its ontogeny. Deacon’s writings are popularist and lack comprehensive scholarly references thus making it difficult to discern what is original and what not. Deacon’s basic thesis is thoroughly anticipated in Pask (1965). The reader might like to consult Pask (2011), which is a collection of Pask’s papers that show the developments in his thinking that lead up to the formulation of conversation theory.

15. For more on these ideas, see Pask (1996), Scott (2007, 2009), Buchinger and Scott (2010). The latter three papers have been published as part of a collection (Scott, 2011).

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