I

I/T Ratio

In classical conditioning - the ratio of intertrial interval to time in the CS. Conditioned responding emerges rapidly when this ratio is high as opposed to low.

Iconic Representation

Iconic representation generally means the representation of perceived experiences or objects through images (icons).

Cross-References

► Mental Imagery and Learning
► Pictorial Representations and Learning

ICT Education

► Courseware Learning

ICT Literacy

► General Literacy in a Digital World

Idea Generation

► Brainstorming and Learning

Identification Learning

Daphne Ari-Even Roth[1], Avi Karni[2]
[1]Department of Communication Disorders, The Stanley Steyer School of Health Professions, Tel Aviv University, Tel-Hashomer, Israel
[2]Department of Human Biology & The E.J. Safra Brain Research Center for the Study of Learning and Learning Disabilities, University of Haifa, Mt Carmel, Israel

Synonyms

Category learning

Definition

Identification learning is a form of perceptual learning that refers to the ability to improve the identification or categorization of stimuli following a learning experience. Perceptual learning is a general term that refers to the improvement in performance on a variety of sensory tasks (e.g., detection, discrimination, identification) that occurs following practice. For example, in the auditory domain, the term *identification learning* can refer to the practice-dependent improvement in the identification of nonnative speech contrasts, or, in the visual domain, to performance gains in the identification of letters. *Identification learning* is a skill (i.e., procedural knowledge) and thus is slowly acquired in an implicit manner; it requires many repetitions, multiple practice sessions, and results in long-lasting gains (Karni 1996). The increased interest in *identification learning* stems from the fact that it has been shown to be a robust learning phenomenon even in adults and thus represents an important model for the study of basic mechanisms of *neural plasticity* and memory that persist beyond childhood.

N. Seel (ed.), *Encyclopedia of the Sciences of Learning*, DOI 10.1007/978-1-4419-1428-6,

Theoretical Background

Identification is related to discrimination abilities, and both processes are considered cornerstones in the ability to categorize. While discrimination is studied by examining the limits on how small a (physical) difference we can tell apart, identification is studied by examining what classes of stimuli we can reliably perceive and label (Harnad 1990). Many categories are innate; other categories are acquired through specific experience, i.e., must be learned. Reliable identification allows us to respond efficiently to novel stimuli or novel situations.

Studies in animals and humans have reported improvement in identification performance following training; robust gains were found even in adulthood. An example for the acquisition of reliable categorization is the *identification learning* of nonnative speech contrasts. This ability has a well-defined developmental trajectory; however, in recent years an adult phase of *identification learning* has been added. It is known that within the first few months of life, the experience of a child with his or her native language robustly modifies the perceptual system so that only those phonetic contrasts that are relevant to the language experience remain distinctive (Kuhl et al. 1992). For example, Japanese infants can easily distinguish between the phonemes/r/and/l/; however, this ability is lost within a few months of experience with Japanese. Adult Japanese listeners have difficulty to differentiate between/r/and/l/even after years of exposure to English (wherein these two phonemes are identified as distinct sound categories). However, contrary to the notion that *identification learning* is limited, if not impossible, in adults, studies in recent years have shown that under appropriate conditions, significant gains in performance were obtained following training to identify/r/and/l/in adult Japanese (Lively et al. 1993).

The notion of a severe limitation on *identification learning* (and perceptual learning in general) beyond early childhood was related for many years to the assumption that the functional properties of neurons within primary sensory processing areas are mutable only during a *critical period of development.* A widely accepted notion was that beyond a certain level of cortical maturation, primary sensory processing (as well as motor) areas are fixed and unchangeable by subsequent experience. There is growing evidence, however, that even basic sensory abilities and skills, i.e., skills that depend on low-level brain representations, can be acquired beyond early life. Studies in different modalities using behavioral, electrophysiological, and imaging techniques show that the adult brain of animals and humans can experience short- and long-term alterations following behavioral training or changes in the sensory inputs. Thus, the adult brain, including primary sensory areas, remains plastic. It has been proposed that following training, long-lasting changes occur in sensory or motor representations that are necessary for the performance of the task. This plasticity may underlie the acquisition and long-term retention of skills (procedural memory) in all of the sensory modalities (Karni 1996).

Robust perceptual learning can be shown in adults even in the case when two well-established phonemic patterns (e.g.,/da/versus/ga/) are presented for identification with increasingly demanding background noise (Ari-Even Roth et al. 2005). This type of experience-driven *identification learning* reflects two general characteristics of adult skill learning; the time course of learning and the specificity of the learning-related performance gains.

The time course of *identification learning* is characterized by two distinct phases: "fast" and "slow" learning. *Fast learning* occurs early on within the initial training sessions and can be induced by a limited number of trials on the order of several minutes. This phase presumably reflects the generation of a stimulus and task-specific processing routine for solving the perceptual problem. *Slow learning* occurs between sessions and involves incremental gains in performance that can be triggered by practice. Slow learning includes a latent phase of several hours duration in which the brain changes consolidate into long-term memory (*procedural memory consolidation; delayed "off-line" gains*). In the case of *identification learning*, time per se can suffice and time-in-sleep is beneficial but may not be necessary. It was suggested that slow learning underlies the gradual development of a specific representation of the emerging skill, a process that requires multi-session practice over several weeks to be completed.

A longer training period may be needed to reach best possible performance in *identification learning* than in detection or simple discrimination tasks.

The ability to generalize the learning gains to untrained conditions (e.g., untrained stimuli, untrained paired organ, untrained task) has been used as a behavioral probe to infer the possible level of the learning-related neural changes (i.e., "where" does learning take place) in different perceptual and motor learning studies. This approach reflects the considerable anatomical and physiological evidence for a hierarchical organization of information processing in sensory systems; many physical parameters of a sensory input are selectively represented only in low-level areas, while neurons in high-level areas respond invariantly to these parameters. In the case of the adult Japanese listeners, more generalization occurred when highly variable stimuli (multiple tokens, multiple talkers) were used in the training sessions than when a single talker or a limited set of tokens were used. Similarly, in the speech in noise identification task transfer to the untrained ear was limited. These results are in line with other studies of perceptual learning wherein changes in low-level representations were implicated.

Important Scientific Research and Open Questions

The study of *identification learning* is of great theoretical importance as it enables us to study the plasticity of the adult brain and the inherent constraints (time course and generalization) on adult skill learning. *Identification learning* is also of clinical importance as understanding the characteristics of adult skill learning, aspects such as the time course of learning and the pattern of generalization after learning, may contribute to the design of effective habilitation training protocols for a variety of populations.

Many important questions regarding *identification learning* remain open. For example, the underlying neural mechanisms are not known; neural correlates have been identified in only a small proportion of the identification tasks. Much work has been done on categorization learning and it is clear that different neural systems are involved depending on the task demands, stimulus properties, and modality. These include the neocortex (sensory-motor, prefrontal), the basal ganglia, and the dopaminergic systems (Seger and Miller 2010). It is of much theoretical as well as practical importance to know whether similar neural mechanisms underlie *identification learning* in different tasks and modalities. Also, it is not clear whether similar neural mechanisms underlie the acquisition of identification skills in children and in adults.

A further question, with many practical implications, is related to the necessary conditions under which effective learning would occur. For example, while attention appears to be necessary in some forms of perceptual learning, under some conditions perceptual learning can occur for features to which focused attention is not directed. It remains unclear whether these different types of perceptual learning share similar underlying mechanisms. Another condition, whose effects are not well understood, relates to the question of whether (and how) sleep and specific sleep stages, contribute to the evolution of delayed gains in performance in *identification learning*. There is growing evidence that sleep may play an important role in the consolidation of skills into long-term memory in adult brains.

Cross-References

► Categorical Learning
► Cognitive Skill Acquisition
► Perceptual Learning

References

Ari-Even Roth, D., Kishon-Rabin, L., Hildesheimer, M., & Karni, A. (2005). A latent consolidation phase in auditory identification learning: Time in the awake state is sufficient. *Learning and Memory, 12*(2), 159–164.

Harnad, S. (1990). Introduction: Psychophysical and cognitive aspects of categorical perception: A critical overview. In S. Harnad (Ed.), *Categorical perception: The groundwork of cognition* (pp. 1–25). New-York: Cambridge University Press.

Karni, A. (1996). The acquisition of perceptual and motor skills: A memory system in the adult human cortex. *Brain Research Cognitive Brain Research, 5*(1–2), 39–48.

Kuhl, P. K., Williams, K. A., Lacerda, F., Stevens, K. N., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science, 255*(5044), 606–608.

Lively, S. E., Logan, J. S., & Pisoni, D. B. (1993). Training Japanese listeners to identify English/r/and/l/II: The role of phonetic environment and talker variability in learning new perceptual categories. *The Journal of the Acoustical Society of America, 94*, 1242–1255.

Seger, C. A., & Miller, E. K. (2010). Category learning in the brain. *Annual Review of Neuroscience, 33*, 203–219.

Identity and Learning

Na'ilah Suad Nasir[1], Tryphenia B. Peele-Eady[2]
[1]Graduate School of Education & Department of African American Studies, University of California, Berkeley, Berkeley, CA, USA
[2]College of Education, Department of Language, Literacy & Sociocultural Studies, University of New Mexico, Albuquerque, Albuquerque, NM, USA

Synonyms

Belonging; Culture and learning; Disciplinary identity; Frames of imagined action; Membership; Self processes and learning

Definition

The relation between identity and learning is complex, involving the interplay of both individual sense-making and social/cultural processes. Identity can be conceptualized as a coherent sense of self that develops throughout the life span. It takes shape in relation to how one is positioned by others and through participation in a range of cultural and communal activities, and is fluid over time and place. In other words, identity involves both individuality and group membership, each governed by internal sense-making processes and expectations and interactions within social and cultural contexts. Learning can be thought of as two kinds of changes: changes in the ways one understands an idea, concept, or process, and concomitant changes in the ways that one takes part in learning activities. Therefore, identity and learning have important implications for one another. One's sense of self and connection to the learning setting influences how one engages activities of learning. Conversely, coming to new ways of understanding confirms individual and group affinities. Thus, identity and learning processes mutually influence one another.

Theoretical Background

Two major bodies of work support our understandings of the ways in which identities and learning relate. The first is grounded in the learning sciences and focuses on how learning processes and disciplinary identities function in learning settings, both in and outside of the context of school. The second is rooted in anthropological and sociological theories of education, and takes up issues of cultural identity and academic achievement. Following, we describe the main contributions of each body of research.

Learning and Disciplinary Identities

One strand of research in this area has studied learning in out-of-school settings, and findings have shown that learning in activities outside of school, such as learning to be a midwife, or learning to become an insurance claims processor, are deeply connected to people taking up an identity in relation to these activities. That is, learning is not just an act of taking in new kinds of information, but also involves becoming a new kind of person (Wenger 1998), in part through the new ways that one is able to imagine oneself and one's future. Another strand of research has focused on learning in classrooms, and has examined the implications that identity has for learning (and that learning has for identity) as students are learning important content in classrooms. In one study, Wortham (2006) studied an upper elementary school classroom and showed that students used the historical concepts they were learning to construct identities for one another in the classroom, as certain kinds of learners. Through this process of students positioning one another, the classroom space made certain kinds of identities available to particular students.

Similarly, literacy researchers have made the argument that not only do identities shape the kinds of literacy practices in which people do and do not engage, but the literacy practices that people take part in play an important role in the learning identities they simultaneously construct. Some of this research has also taken into account the ways that structurally defined identities, like race, class, or gender, can be both reified and challenged in schools and classrooms. Like Wortham, these scholars argue that the literacy classroom can be a place of identity construction and negotiation, and that the nature of what counts as valued learning in classrooms matters for students' opportunities to take up identity as readers, writers, and learners. Researchers in mathematics education have further explored the connection between students' identities and their desire to pursue learning in the future. Boaler and Greeno (2000), for example, studied learning in two different kinds of math classrooms, and found that the type of instruction available to students influenced how connected students felt to the discipline of mathematics, and when they had stronger mathematics identities (i.e., when they felt more connected to the discipline) students were more likely to express interest in pursuing more mathematics learning in the future.

Culture and Learning

The other major body of research relevant to understanding the relation between learning and identity is the corpus of research on the relation of culture and learning. This tradition of research views identity as being inherently linked to cultural expectations and norms of social belonging. Educational anthropologists like Gonzalez (1999) have argued that the terms *identity* and *culture* are sometimes used interchangeably, and that while they are not exactly identical, they do share a common root – they are both constructed through language. As Gonzalez writes, "it is through and by language and discursive practices that selfhoods are constructed, identities are forged, and social processes are enacted" (Gonzalez 1999, p. 433). Several studies highlight the cultural and linguistic processes through which individuals develop ideas about themselves as learners. Much of this literature has framed school as both central to students' lives and a direct reflection of societal structure; thus connecting learning and learning identities to broader sociocultural and sociopolitical expectations, stereotypes, and positioning.

Learning is also fundamentally related to the ways students construct different racial, cultural, and gendered images of themselves across varied contexts, including schools. For example, in a study of cultural identity and learning Davidson (1996) highlighted the ways that negative stereotypes about African American and Latino students were conveyed or dismantled within classroom learning settings, and the varying ways students took up or rejected these negative academic stereotypes as they engaged these settings. When others viewed students as being less capable academically by virtue of their race, and schools were structured in line with these negative expectations, students had fewer opportunities to develop a positive sense of themselves as learners. This and other research (e.g., Horvat and O'Connor 2006) supports the idea that what happens within school and classroom contexts has a direct effect on the identities that young people take up both in relation to race and culture and in relation to learning. This perspective on identity, similar to that in the learning sciences, views learning identities not as solely internally constructed, but rather linked to the external opportunities learners have to see themselves as successful.

Important Scientific Research and Open Questions

The relationship between identity and learning processes is complex and multifaceted. While learners are agentic in constructing identities for themselves, identities are also assigned and ascribed to learners by others, and by the social contexts in which learners engage. Therefore, a critical task for research in this area is to develop (and explore) conceptions of identity that foster a treatment of it as a process that involves both agency and structure. Capturing this complexity raises important methodological issues. First is how best to study learning and identity as macrolevel concepts, including individual and sociocultural aspects. Such exploration will reveal more about the intertextual relationship between learning and identity – that is, how identity takes shape in relation to learning and how learning happens in relation to identity. Further, we also need critical reflections of identity and learning at the microlevel, as we consider how young people take up, translate, and then draw on these conceptions in their everyday school experiences as both individuals and as members of peer groups, school and classroom communities, and other participant structures centering on instruction.

Cross-References

► Activity Theories of Learning
► Apprenticeship Learning in Production Schools
► At-Risk Learners
► Authenticity in Leaning Activities and Settings
► Communities of Practice
► Development and Learning
► Development of Self-Consciousness
► Learning Identity
► Learning in Conflictual Practice
► Trajectories of Participation

References

Boaler, J., & Greeno, J. G. (2000). Identity, agency, and knowing in mathematics worlds. In J. Boaler (Ed.), *Multiple perspectives on mathematics teaching and learning* (pp. 171–200). Westport: Ablex Publishers.

Davidson, L. (1996). *Making and molding identities in schools.* Albany: State University of New York Press.

Gonzalez, N. (1999). What will we do when culture does not exist anymore? *Anthropology and Education Quarterly, 30*(4), 431–435.
Horvat, E., & O'Connor, C. (2006). *Beyond acting white.* NY: Rowan & Littlefield.
Wenger, E. (1998). *Communities of practice: Learning, meaning and identity.* Cambridge: Cambridge University Press.
Wortham, S. (2006). *Learning Identity: the joint emergence of social identification and academic learning.* New York: Cambridge University.

Further Reading
Lave, J., & Wenger, E. (1991). *Situated learning and legitimate peripheral participation.* Cambridge: Cambridge University Press.

Ideo-motor Principle of Learning

► Anticipatory Learning

If–Then Reasoning

► Conditional Reasoning by Nonhuman Animals

If–Then Rule Learning

► Conditional Reasoning by Nonhuman Animals

Illative Faculty of the Mind

► Inferential Learning and Reasoning

Illegal Activity

► Delinquency and Learning Disabilities

Illusions of Causality

► Causal Learning and Illusions of Control

Imagery

► Learning by Doing Versus Learning by Thinking
► Mental Imagery

Imagery and Learning

► Mental Imagery and Learning

Imagery Therapy

► Metaphor Therapy

Images

► Pictorial Representations and Learning

Imagination

The awareness of sensory qualities in the absence of appropriate external stimuli.

Cross-References

► Mental Representations
► Openness to Experience

Imagination Effect

Paul Ginns
The University of Sydney, Sydney, NSW, Australia

Synonyms

Mental practice; Mental rehearsal; Mental simulation; Visualization

Definition

The ► imagination effect is generated when instructions to imagine a series of steps required to solve a problem, paired with practice problems, generate better learning outcomes than instructions to study (read through and understand) equivalent instructional materials.

Theoretical Background

Mental practice, visualization, and imagination are members of a class of cognitive processes which have been found, under some circumstances, to enhance learning. Each of these processes involves quasi-sensory conscious experiences, and "have in common the awareness of sensory qualities in the absence of appropriate external stimuli" (Anderson 1981; p.150). Anderson notes that while the term "imagery" has a visual connotation, it need not be restricted to this modality, and recommends using the term "imaginary" over "imaginal" to reduce the visual connotation when discussing such phenomena. The use of such processes for learning dates back at least to Ancient Greece (e.g., the Method of Loci), but imaginary processes have also provided the basis for several more recently developed mnemonic learning techniques. Imaginary mnemonics are generally used for learning declarative information (e.g., facts, vocabulary). In contrast, the term mental practice has traditionally been used in the context of developing procedural knowledge, such as physical or cognitive skills. Using meta-analytic methods, Driskell et al. (1994) concluded that mental practice, "…the symbolic, covert, mental rehearsal of a task in the absence of actual, overt, physical movement" (p. 481), enhances learning across a broad range of motor, perceptuo-motor, and cognitive skills.

The range of skills examined in Driskell et al. (1994) review included few examples of skills of a largely cognitive form: that is, skills for which a physical component is minor or even trivial. One theory of instructional design that has focused strongly on how cognitive skill development can be fostered is Cognitive Load Theory (CLT). CLT takes as its starting point our fundamental knowledge of the mind's structure and how it processes information – our cognitive architecture. For the purposes of instruction, cognitive load theory focuses on two fundamental components of this architecture. The first component is a working memory which is severely limited in both capacity and duration, while the second is a long-term memory which is effectively unlimited in capacity. ► Schemas in long-term memory, which may be partially or fully automated through extended practice, provide the basis for problem-solving expertise.

CLT argues the interplay between these components of the cognitive architecture is of fundamental importance in learning. Although working memory capacity is limited with respect to the number of elements it can process at any given time – including during learning – those elements themselves may encode a vast amount of information, in the form of schemas activated from long-term memory into working memory. For instance, an expert reader does not have to expend mental effort in decoding the components of individual letters to derive meaning from a text. His or her automated schemas for reading, developed through years of practice, allow recognition of the meaning of letters, whole words, or possibly even sentences and paragraphs, with little or no expended cognitive effort. Partially or fully automated schemas thus allow available cognitive capacity to be directed toward encoding novel features of the materials at hand into long-term memory; that is, learning. As discussed below, CLT argues the degree to which a student will benefit by imagining rather than studying instructional materials will depend on prior knowledge levels, that is, schemas in long-term memory.

Important Scientific Research and Open Questions

The ► imagination effect (Cooper et al. 2001; Ginns et al. 2003) occurs when learners benefit more from closing their eyes or looking away and imagining the steps involved in solving a problem demonstrated in a worked example, rather than studying such materials (i.e., reading through and attempting to understand the solution steps).

Cooper et al. (2001) and Ginns et al. (2003) both identified prior knowledge as a moderator of the effectiveness of imagination. In cross-sectional experiments (i.e., studies using samples of students with varying levels of prior knowledge), learners with lower levels of prior knowledge benefited more from instructions to study worked examples, whereas students with higher levels of prior knowledge benefited more from instructions to imagine the same worked examples. Drawing on the theoretical framework outlined above, these results were explained as follows. For less knowledgeable students, instructions to study facilitate the development of schemas, as they focus the learner's attention on the structure of the problem and how to reach a solution. For more knowledgeable students, who already have a higher degree of relevant schematic knowledge, instructions to study will be largely redundant – in studying, such students will simply be reiterating the mental processes that allowed them to construct the schema in the first place. In contrast, instructions to such students to imagine the steps in a solution are not redundant, as they require those students to look away from the instructional materials and rely on their own schematic understanding while imagining, rather than external instructional guidance. Cooper et al. and Ginns et al. argued a general sequence of study (supporting initial schema construction) then imagination (supporting schema automation) will support learning more than a sequence of imagination then study, an hypothesis supported in two separate longitudinal learning experiments comparing these alternative sequences. The key role of prior knowledge levels in generating imagination effects led Kalyuga et al. (2003) to class the imagination effect as an example of the *expertise reversal effect* – the tendency for the effectiveness of CLT-based instructional designs to change (e.g., disappear or even reverse) as expertise in a given area increases.

Experiments investigating the imagination effect have so far depended on either broadly defined measures of prior knowledge to operationalize expertise, such as class-wide mathematics test scores; knowledge of parts of the curriculum students have and have not studied; or self-report of knowledge levels in a given domain (e.g., Cooper et al. 2001; Ginns et al. 2003). While these have proved sufficient for demonstrating interactions between prior knowledge and the imagination effect, there is no empirically validated quantitative metric, based on domain-specific schemas, currently available that would allow judgments to be made about readiness for imagination. The development of such a metric would support accurate diagnosis of current schema levels, thus allowing learner-adapted dynamic instruction based on an appropriate mix of study and imagination. Such a metric should help teachers identify if a student has unified several related elements of information into a single schema capable of being held in its entirety in working memory, meaning that he or she is capable of imagining the schema.

Kalyuga and Sweller (2004) developed a method for rapidly assessing whether a student possesses a schema for a given problem, based on measuring the extent to which a student can correctly state the first step in solving a given class of problems. They found performance on such tests was highly correlated (up to .92) with more traditional tests of knowledge in algebra and coordinate geometry (Experiments 1 and 2), with substantial savings in assessment time using the rapid assessment test. In subsequent experiments, they demonstrated that when the rapid schema assessment method was used to assign learners to instructional conditions consonant with their knowledge levels, these students outperformed students who viewed instructional materials that were either dissonant (Experiment 3) or random (Experiment 4) with respect to their knowledge levels. These results suggest that the rapid test method might also be used by educators to determine when a student would benefit from switching from studying to imagination. A high score on a rapid test would indicate the student has constructed a schema capable of being held in working memory, and that further study at this point would be redundant. Imagination, in contrast, should act to automate the already constructed schema, enhancing learning.

Cross-References

- ▶ Cognitive Load Theory
- ▶ Cognitive Skill Acquisition
- ▶ Expertise
- ▶ Mental Imagery and Learning
- ▶ Mnemonic Learning
- ▶ Schema(s)

References

Cooper, G. A., Tindall-Ford, S., Chandler, P., & Sweller, J. (2001). Learning by imagining. *Journal of Experimental Psychology: Applied, 7*, 68–82.

Driskell, J. E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *The Journal of Applied Psychology, 79*, 481–492.

Ginns, P., Chandler, P., & Sweller, J. (2003). When imagining information is effective. *Contemporary Educational Psychology, 28*, 229–251.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*, 23–31.

Kalyuga, S., & Sweller, J. (2004). Measuring knowledge to optimize cognitive load factors during instruction. *Journal of Educational Psychology, 96*, 558–568.

Further Reading

Anderson, M. P., et al. (1981). Assessment of imaginal processes: approaches and issues. In T. M. Merluzzi, C. R. Glass, & M. Genest (Eds.), *Cognitive assessment*. New York: Guilford Press.

Imaginative Learning

Carolyn A. Maher[1], John M. Francisco[2], Marjory F. Palius[1]
[1]Graduate School of Education, Rutgers University, New Brunswick, NJ, USA
[2]School of Education, University of Massachusetts, Amherst, MA, USA

Synonyms

Aesthetic imagination; Creativity; Enrichment; Inquiry in learning

Definition

Imaginative learning refers to how learners explore their environments in creative ways. This learning can take place within multiple content areas and contexts, and across all ages. Imaginative learning is an approach to learning that respects the creativity of learners and values motivation that promotes inquiry, investigation, collaboration, experimentation, and personal ownership of ideas and ways of working (Maher 2005). An appreciation for imaginative learning is especially emphasized in the Arts. Writing for the Lincoln Center Institute, Holzer (2007) suggests nine capacities that can be used to characterize imaginative learning. These are noticing deeply, embodying through senses, questioning, making connections, identifying patterns, exhibiting empathy, creating meaning, taking action, and reflecting/assessing (Holzer 2007, p. 5). However, many of these same capacities are present in imaginative learning, when it occurs, in a variety of disciplines, such as in mathematics, science, and the humanities. Interest in promoting imaginative learning in any discipline through seeking to foster creativity can serve as a guide to educators in their teaching and preparation of programs for building meaningful knowledge by engaged and motivated learners. It is also valued in enrichment learning in schools within a variety of disciplines. Imaginative learning is found in problem-based learning in the area of psychology. In the area of artificial intelligence technology and robotics, imaginative learning is a central feature. Collaborative work also tends to evoke imaginative learning.

Theoretical Background

The *idea* of imaginative learning can be traced to the work of John Dewey. According to him, learning evolves from experiences that come about as a consequence of a learner's actions, as they engage in meaningful inquiry and reflective thinking (Dewey 1938). An elaboration of Dewey's view is offered by Lawrence (2010) in what he calls *investigative reasoning:*

- Solutions that come out of investigative reasoning may or may not be sanctioned by authorities or be considered as data in the pool of things being considered. But the investigative test is whether the new idea fits the requirements of the situation that triggered the reasoning. This inquiry tries out ideas both in imagination and in action by examining the consequences of the chosen action. (Lawrence 2010, p. 59)

Imaginative learning is connected to inquiry and playful investigation, where learners engage in problem solving and investigative reasoning with absorbing interest and concentration (Lawrence 2010). In both imagination and action, imaginative learners build personal and meaningful representations of ideas that help them make sense of new, challenging situations. They do so in a number of ways. They are *careful observers*, they view situations from different perspectives and represent them in a variety of creative and original ways. The varieties of ways they represent their ideas include models, symbols, diagrams, notations, drawings, and rules. As they draw on input from others in *collaborative work*, they *invent new ideas and* come up with more sophisticated ones. In *revisiting situations*, they review, revise, and rebuild as interest and experience suggest. Imaginative learners pursue personally meaningful ways of working (Davis and Maher 1990; Maher 2005).

A number of conditions foster imaginative learning. There have to be opportunities for *playful, meaningful, hands-on investigations* to inspire and initiate the interests of the imaginative learner (Lawrence 2010). This means that the environment in which imaginative learners achieve satisfaction is based on their own interests and choices, leading to their own creative work. In their pursuit of knowledge, they may engage in risk taking, and thus need *a safe and nurturing environment* along with opportunities to explore, invent, and collaborate. *Ownership of learning* for imaginative learners is essential. In this way, their search for creative expression provides personal benefits from their choices. Another crucial condition is that there be plentiful time allotted to engage in investigations (Maher 2005).

Important Scientific Research and Open Questions

Seminal research in the field of mathematics education, particularly a longitudinal study that has followed a cohort of learners from first grade through high school and beyond (Maher 2005), yields numerous examples of imaginative learning. Some of these examples have been featured in *The Private Universe Project in Mathematics* (Harvard-Smithsonian 2001), and two are selected for illustrative purposes here.

Brandon is a 10-year-old boy from a school district that participated in the cross-sectional phase of longitudinal research that studied how children build mathematical ideas and used video to document problem solving and follow-up interviews. In his fourth-grade classroom, children worked with a partner to explore some cognitively challenging tasks in the combinatorics strand of mathematics. Importantly, conditions were created that gave children plenty of time to work on the problems posed and offered them the freedom to structure their own investigations (Maher 2005). The role of the adults were as teacher-researchers, and they functioned to facilitate imaginative learning by inviting children to engage in problem-solving activities and inviting students or groups to decide how they would approach the problem and work toward its solution. One problem involved building block towers of height four when selecting from two colors, red and yellow, of unifix™ cubes. They were asked to find all possible four-tall tower combinations, and to convince themselves and others that they found them all and had no duplicates. Brandon and his partner worked on this task as a playful, meaningful, hands-on investigation during a math period that was extended to 1 full hour. In addition to building towers with the manipulatives, children represented their solutions on paper using the personal notation that they created. During another classroom session, Brandon and his partner worked on a different combinatorics task. This time they were asked to find all the possible choices for ordering pizza when selecting from four different toppings: sausage, pepperoni, mushrooms, and peppers. Once again, the children were free to decide how to represent their ideas in a way that made sense to them. After working on the pizza problem, Brandon participated in an interview with the teacher-researcher to discuss his problem solving. This interview appears in *The Private Universe Project in Mathematics* (Harvard-Smithsonian 2001).

During the interview, the teacher-researcher asks Brandon to share his ideas and explain the way he represented his solution to the pizza problem. In the video, we see Brandon recreate a chart like the one he had produced in class, which has four columns that he labels to represent the choices of pizza toppings. In rows beneath, he systematically lists the possible choices using notation of 1 when the topping is present on the pizza and of 0 when it is absent. He starts with a plain pizza (no toppings), then one-topping pizzas, then two-topping pizzas, then three-topping pizzas, and finishes with all four toppings. When asked where he got the idea for 0–1 notation, Brandon said "it just popped into my head" (Harvard-Smithsonian 2001). The teacher-researcher next asks if the pizza problem reminded him of any other problems they did in class, and Brandon replied that it is "the same" as towers. To explain more fully, Brandon builds all the possible towers four-cubes tall when selecting from red and yellow cubes. He organizes them by cases, starting with no red (all yellow), then one red (three yellow), then two red (two yellow), then three red (one yellow), and finally all red (no yellow). In the video, we see Brandon discover the isomorphism between the two problems, and see the power in his ownership of ideas in that he readily acknowledges that red could stand for 0 and yellow for 1, or vice versa (Harvard-Smithsonian 2001).

A second example of imaginative learning comes from the 1999 Summer Institute of the longitudinal study; this time with rising seniors in high school exploring a problem in the precalculus strand of mathematics. The students have been given copies on paper and transparencies of Muybridge's cat photographs taken around 1880, which show a series of 24 photographs taken with an interval of .031 s between successive frames that show a cat, first walking and then running. The cat is moving in front of a grid whose lines are 5 cm apart, with some grid lines darker than others. The students are told that those photographs, as the only information available about the cat, should form the basis for responding to the following two questions: (a) How fast is the cat moving in frame 10? (b) How fast is the cat moving in frame 20? Each of the 17 students has a graphing calculator and, although working in three groups to explore the problem, they are free to move about and talk with any of the other students during the multiday period devoted to this task. They use the calculators to produce graphs and tables, and then share their work with everyone at the overhead projector. Through collaboration, the students make use of both calculator graphs tabulating average velocity from one frame to the next and linear representation of the total distance traveled by the cat. They come to see the cat's position as a function of time, and it sparks the desire among the students to enact how they, too, could move like the cat. Using masking tape along the floor in the hallway, they mark off the 24 lines corresponding to the cat's position in each frame, but scaled up by a factor of 50, to produce a line just over 65 m in length. Using an improvised drum, one student beats a regular rhythm while several students take a turn at moving down the line trying to reach each mark as the corresponding drumbeat sounds (Harvard-Smithsonian 2001).

In the first example, Brandon's creativity is evident in two ways: (1) he invents a representation of the problem situation based on 0s and 1s; and (2) he imagines a transfer of the representation of his solution of the pizza problem to solve a different problem, thus establishing the isomorphism between the problem situations. In the second example, the students' creativity is evident in their imagining *being* the cat and of enacting the cat's run. In so doing, they gained a richer understanding of the problem situation than they were able to gain from written representations such as graphs, drawings, and notations. Both examples describe the imaginative learning in *doing* mathematics. Video examples of students engaged in imaginative learning can be found in the Rutgers University Repository at: http://videomosaic.org/.

While these two examples of imaginative learning come from mathematics education, Lawrence (2010) notes others drawn from science education; videos of imaginative science education can be viewed from the Harvard Smithsonian web site: www.learner.org.

Cross-References

► Mathematical Learning
► Play, Exploration and Learning
► Problem Solving

References

Davis, R. B., & Maher, C. A. (1990). What do we do when we do mathematics? In R. B. Davis, C. A. Maher, & N. Noddings (Eds.), *Constructivist views on the teaching and learning of mathematics* (Journal for Research in Mathematics Education Monograph, Vol. 4, pp. 65–78). Reston: National Council of Teachers of Mathematics.

Dewey, J. (1938). *Experience and education.* New York: Collier Books.

Harvard-Smithsonian Center for Astrophysics Science Media Group (Producer). (2001). The private Universe project in mathematics: problems and possibilities. [Six one-hour videotapes highlighting the combinatorics, probability and pre-calculus strands of C. Maher's longitudinal study (in its twelfth year)]. Anneberg/CPB at www.learner.org

Holzer, M. F. (2007). *Aethestic education, inquiry and the imagination.* New York: Lincoln Center Institute for the Arts in Education.

Lawrence, G. D. (2010). *Finding the zone.* New York: Prometheus Books.

Maher, C. A. (2005). How students structure their investigations and learn mathematics: Insights from a long-term study. *The Journal of Mathematical Behavior, 24*(1), 1–14.

Imagined Worlds

► Cognitive Artifacts, Technology, and Physics Learning

Imitation

► Social Cognitive Learning
► Social Learning

Imitation and Social Learning

Karl H. Schlag
Department of Economics, University of Vienna, Vienna, Austria

Synonyms

Copying, acquiring knowledge within a group

Definition

Imitation is the act of copying the behavior of someone observed. It is the most common learning rule and, as behavior, can be observed among animals (Galef and Laland 2005) as well as among humans (Apesteguia et al. 2007; Horner and Whiten 2005). Not to imitate means to experiment or innovate, to try something new instead of choosing one of the behaviors that has been observed.

To learn means to acquire knowledge or understanding. Social learning is about learning within a social group as opposed to individual learning where only the learning of a single person is considered. Concern is for how individuals within the group learn, and hence how the whole group learns. Social learning does not require that individuals within the group actively change their understanding about the environment. To exhibit learning as a group, it is already sufficient that more within the group adapt a superior action.

Theoretical Background

Imitation is a simple behavior that has two basic ingredients. One needs to be able to observe what others have done and one needs to be capable of doing what they have done. Often one is also able to observe the consequences of their choices. However, one does not need to understand why someone observed has made this specific choice nor understand how this choice has generated the observed performance.

To imitate means to economize on explicit or implicit costs of evaluating each possible choice. Its virtues are clearest when others have superior information. Not much theory is needed to explain why imitation is valuable under such circumstances. If someone else knows what is best and faces the same situation, then it is best to (unconditionally) imitate this person.

In this entry a theory is presented that demonstrates why imitation can be valuable even if no individual has superior information. We show how imitation can enable the group to aggregate the different experiences of its members. Again, there are not many new insights if individuals face an environment where there is no variability in the performance of an action, when the same action always yields the same payoff. In such an artificial setting, imitation of someone who has performed better improves one's own performance. But what if there is variability in the performance of an action? This is the more natural setting. In the following we allow the performance of an action to depend on the current state of the environment, so that an action that sometimes performs well may perform badly on other occasions. What is the value of imitation for the person and for those in the group that are observing each other? It is the value of imitation in this context of social learning that we wish to identify and to qualify. The original arguments can be found in Schlag (1998), for a nontechnical treatment see Alos-Ferrer and Schlag (2009).

We will be considering a group of individuals who repeatedly make choices in the same environment. Between choices, each meets someone else within the group and observes the action and performance of the other. We wish to answer two questions: Why imitate, and if so, then when? The "why" is simple. It is in order to aggregate individual experiences, based on an understanding that the social group together has more information than each separate member. In the case of effective social learning behavior, an action that is used by more individuals will reflect that this action is on average more successful. Hence, information on the success of each action will implicitly be stored by the frequencies with which they are used in the group. The question when to imitate seems obvious if the performance of others is observable. It seems most plausible to imitate those that have performed better, a rule called *Imitate if Better*. It is theory that helps us to understand why this is generally not the right thing to do. It is theory that helps us identify what aspects of imitative behavior we should look for, and in what types of environments imitation is more likely to be valuable. Not until we have an understanding of which rules are best can we make predictions about social learning with an understanding that results are not driven by an ad-hoc choice of behavior but instead by behavior that is in some sense optimal.

Important Scientific Research and Open Questions

Imitate if Better is the classic behavior (or rule) that is associated with imitation if only one other is observed. We start by explaining why this behavior need not have good properties. To imitate those that perform better can induce, on average, more to choose an inferior action. In fact, if there are many in the group then it can be very likely that all choose an inferior action in the long run. The reason is that those that perform better need not be choosing a better action when performance itself is variable (or noisy). One needs to see an example to completely understand this counterintuitive result. Assume that all individuals are using Imitate if Better. Assume that there are two actions D and N. Action D is deterministic in the sense that it always yields a payoff equal to 0.1. Action N is noisy and yields 40% of the time the value 1 and 60% of the time the value 0. In terms of average performance, N is the superior action. The average payoff of N is $0.4^{*}1+0.6^{*}0=0.4$ which is larger than the (average) payoff of D which is equal to 0.1. Now consider two individuals seeing each other, one using D and the other using N. 60% of the time, so in 60% of such matches, N yields 0, and hence the individual using N switches to D. 40% of the time the individual using N gets payoff 1 and hence the individual using D switches to N. Thus, the likelihood of a switch from N to D is 60% while that of a switch from D to N is 40%. It is more likely that there will be a switch from N to D than vice versa. In the next round one expects more to play D. The number of those choosing the superior action N is expected to decrease. If there are many individuals, with initially both D and N being chosen, then it is easy to prove that with a large probability no one will choose the superior action N in the long run.

Is this environment too complex for simple learning rules to perform well? No, Imitate if Better is simply not the appropriate rule to use. In fact, on closer look, it is not that intuitive. While imitation of those that perform better sounds appealing when one's own payoff is 0.1 and observed performance is 1, it is much less appealing when one's own payoff is 0 and observed payoff is 0.1. The difference in performance should play a role, and it does, both behaviorally (Apesteguia et al. 2007) and theoretically. Consider the following alternative imitation rule called the Proportional Imitation Rule (Schlag 1998). Never imitate anyone who performed worse. Do not always imitate those that do better, but instead choose the probability of imitating the observed proportional to how much better the observed performed. We illustrate with the above example. This means to choose a constant $\sigma > 0$, not too large, that is common for all in the group and then to switch when using D and observing N with payoff 1 with probability $(1–0.1)\cdot\sigma=0.9\cdot\sigma$ and when using N, receiving payoff 0, and observing D to switch with probability $0.1\cdot\sigma$. The increase in choice of N among those pairs where D observed N is then equal to $0.4\cdot0.9\cdot\sigma – 0.6\cdot0.1\cdot\sigma = 0.3\cdot\sigma$. Hence more are expected to choose the superior action N in the next round.

So why not choose the superior action N at the start? Typically, information about the underlying process is limited, i.e., we do not know that N is superior. The decision theoretic solution to learning under limited information, Bayesian learning, is to first (subjectively) assess the likelihood of each possible environment and then to choose what is best, given the information one gathers over time. This is not very practical as it does not tell us how to determine these likelihoods. Moreover, updating choice based on information is extremely difficult even in the simplest of situations. Instead of searching for a rule that is best according to such a specific subjective assessment we search for a rule that is good in all environments and hence does not require such a subjective assessment. We search for one rule that on average causes performance in the population to increase over time regardless of how payoffs are generated. This captures learning in its most basic notion as it only relies on minimal a priori knowledge, in contrast to decision theoretic (or Bayesian) learning which is more about updating initial assessments (or beliefs).

So, what kind of rules are good in all environments when all use the same rule? They have to be imitative: either choose previous action again or switch to the action of the observed. Otherwise, if some individuals go off trying new actions not observed then these may be inferior to those currently used in the population and hence can reduce overall payoffs in the population. Imitate to avoid making mistakes. Use a rule that is responsive to the magnitudes of performance. For instance, Imitate if Better did not perform well. In fact, it turns out that only a small class of imitation rules does the job. Among these one can argue that the Proportional Imitation Rule (PIR) is best. Of course, when all use the PIR, then some may do worse in the next round, however, others will do better in a way that average performance in the population is expected to increase over time. PIR incorporates differences in performance in behavior to wash out good luck and bad luck and to focus on average performance. From a broader perspective we find that society can function as a storage or memory of the success of strategies, where the success of a strategy is mirrored by the proportion of individuals choosing it. Strategies can only remain popular over time if they are superior. For individuals within this population we find a particular form of random behavior to be valuable as switching to those that did better is probabilistic. To act probabilistic means to incorporate the magnitude of performance into one's own behavior. When all use PIR, then the frequencies of choices made within the population evolve according to the replicator dynamic (known from evolutionary game theory). This connects social learning dynamics with asexual reproduction dynamisms (Weibull 1995).

Once we have derived the simple but insightful result above, we can discuss the role of assumptions that our logic is based on. In what types of environments is the above true? The environment has to be stationary in the sense that each action generates either a constant or a noisy payoff where the underlying process generating payoffs does not change over time. Individuals must be identical in the sense that the payoff generated by an action may not depend on which individual chooses this action. In particular, payoffs should not depend on what others choose in the group. Payoff differences must be bounded as switching occurs with probability equal to σ times the difference in payoffs, where σ is the same for all environments, and this probability has to be bounded above by 1.

When is *Imitate if Better* a good rule? It is best among imitation rules when the performance of actions is not subject to noise. It is also a good rule (Schlag 1998) when noise is idiosyncratic, which means that the payoffs generated by any two actions only differ according to their mean and not according to other properties of their distribution such as variance (as assumed in the location shift model of statistics and when referring to homoscedastic errors in econometrics). Here payoff differences do not have to be bounded.

>Above, we assumed that performance of others is observable. What should one do when one does not observe their performance and one only observes their behavior? Use the proportional reviewing rule that is defined as follows. Draw a threshold, each threshold being equally likely, and switch if own performance lies below this threshold. It is as if one is using a satisficing rule (cf. Simon 1955) where the aspiration level above which one is satisfied is drawn according the uniform distribution.

Up to now we have assumed that each individual only observes one other individual between making choices. What should one do if the individual observes the behavior and the performance of two or more others? It is hard to compare rules. However, one rule that performs well is the sequential proportional observation rule (Hofbauer and Schlag 2000). This rule prescribes to place the observed individuals in a random order, to then consider each individual one by one, to imitate the action of the next in line with probability proportional to the observed payoff, and then to continue to the next. Population dynamic approaches the adjusted replicator dynamic when many are observed, a further connection between social learning and evolutionary game theory (Weibull 1995). Note that this behavior is based on the proportional observation rule, to imitate the observed with probability proportional to the performance of the observed, empirically found to be relevant for understanding the behavior of fish (Pike et al. 2010).

Above, we observed that *Imitate if Better* is a good rule when noise is idiosyncratic and one other is observed. But what if noise is idiosyncratic and many others can be observed? One might think that one should imitate the action that performed best on average. However, this rule does not induce good social learning properties. Averaging washes out noise which is good for understanding the value of a choice used by the majority. However, this is unfavorable when compared to a choice only used by few when noise is not symmetric. An inferior choice that sometimes generates very bad outcomes can spread when used by few if it is likely to generate outcomes above that of the majority choice. Concern for average performance is only a good rule if one is comparing groups where each choice is used by many. In order to allow for comparisons of many with few (and many with many) one should imitate the action of the individual that performed best (Schlag 1996).

What is the role of innovation? If all use an imitative rule then there will never be any innovation, no new action will ever be introduced. Innovators are needed for progress; they have to be willing to experience failures. In contrast, society based on imitative behavior has the ability to avoid failures in the aggregate and yet to adapt actions introduced by innovators and to test them against the existing strategies.

There are numerous open questions in the literature.

What if there are more prominent members in society, members that are more likely to be observed than others? We provide some intuition for the case where each individual only observes one other. The key to all results presented above is that there should be no expected change when both actions have the same average performance. So those observing a prominent member should anticipate that many are switching when adapting this person's action while only one switches, namely the prominent member, when the normal members performs better. To illustrate, assume that a prominent member is observed twice as likely as a normal member. Then normal members have to downscale their switching propensity from the rate σ used by the prominent member to $\sigma/2$.

What if the probability of observing someone depends on that person's performance? This sampling bias has to be taken into account which in special cases is easy to do. For instance, assume that each individual is matched with another one but only observes that person's choice with probability that is proportional to her performance. Then a good rule is to imitate whenever possible. Here good performance of the rule rests on the assumed linear relationship between observability and performance.

Other important open topics for future research include giving up the assumption that all use the same rule (cf. Bjornerstedt and Schlag 1996), investigating how to deal with memory, how to learn from others facing similar but different situations, and how to deal with changing environments.

The key to this research is to accept and model limits on information and knowledge, to consider simple objectives and to then gain insights into optimality of behavior that sounds plausible, like imitation. Insights can be valuable across many disciplines including anthropology, population biology, decision theory, and economics. Theory shows where to look in the data (e.g., see Apesteguia et al. 2007; Kendal et al. 2009; Pike et al. 2010). Once one has identified which rule is best one can make predictions. For instance, an investigation of the replicator dynamics (Weibull 1995) can now be understood as an analysis of the outcome of "optimal" social learning with limited information.

In summary, there is more to imitation than simply copying behavior of others. To be an effective social learning rule, thus to induce the group over time to choose superior actions, each individual has to look at differences in performance before deciding whether to imitate. A very simple rule that determines when to imitate and only relies on the ability to observe behavior of one other yields effective learning even when there is variation in individual performance. Learning becomes possible as society functions as storage of what has been successful, more successful choices being adapted by more individuals.

Cross-References

- ► Bayesian Learning
- ► Bounded Rationality and Learning
- ► Imitation: Definitions, Evidence, and Mechanisms
- ► Imitative Learning in Humans and Animals
- ► Individual Learning
- ► Learning and Evolution of Social Norms
- ► Learning and Evolutionary Game Theory
- ► Reinforcement Learning
- ► Social Learning

References

Alos-Ferrer, C., & Schlag, K. H. (2009). Imitation and social learning. In P. Anand, P. Pattanaik, & C. Puppe (Eds.), *The handbook of rational and social choice*. Oxford: Oxford University Press.

Apesteguia, J., Huck, S., & Oechssler, J. (2007). Imitation – theory and experimental evidence. *Journal of Economic Theory, 136*, 217–235.

Bjornerstedt, J., & Schlag, K. H. (1996). *On the evolution of imitative behavior*. Discussion Paper No. B.378, Sonderforschungsbereich 303, University of Bonn.

Galef, B. G., Jr., & Laland, K. N. (2005). Social learning in animals: Empirical studies and theoretical models. *Bioscience, 55*(6), 489–499.

Hofbauer, J., & Schlag, K. H. (2000). Sophisticated imitation in cyclic games. *Journal of Evolutionary Economics, 10*(5), 523–543.

Horner, V., & Whiten, A. (2005). Causal knowledge and imitation/emulation switching in chimpanzees (*Pan troglodytes*) and children (*Homo sapiens*). *Animal Cognition, 8*, 164–181.

Kendal, J. R., Rendell, L., Pike, T. W., & Laland, K. N. (2009). Nine-spined sticklebacks deploy a hill-climbing social learning strategy. *Behavioral Ecology, 20*(2), 238–244.

Pike, T. W., Kendal, J. R., Rendell, L. E., & Laland, K. N. (2010). Learning by proportional observation in a species of fish. *Behavioral Ecology, 21*(3), 570–575.

Schlag, K. H. (1996). *Imitate best vs. Imitate best average*. Mimeo, University of Bonn. http://homepage.univie.ac.at/karl.schlag/research/imitation/IDIO9.pdf.

Schlag, K. H. (1998). Why imitate, and if so, how? A boundedly rational approach to multi-armed bandits. *Journal of Economic Theory, 78*(1), 130–156.

Simon, H. A. (1955). A behavioral model of rational choice. *Quarterly Journal of Economics, 69*(1), 99–118.

Weibull, J. (1995). *Evolutionary game theory*. Cambridge: MIT Press.

I

Imitation in Networks

► Naïve Learning in Networks

Imitation Learning

► Apprenticeship Learning in Machines
► Robot Learning from Demonstration

Imitation Learning in Robots

Aude Billard, Daniel Grollman
EPFL, Lausanne, Switzerland

Synonyms

Learning/programming from/by demonstration; Through apprenticeship

Definition

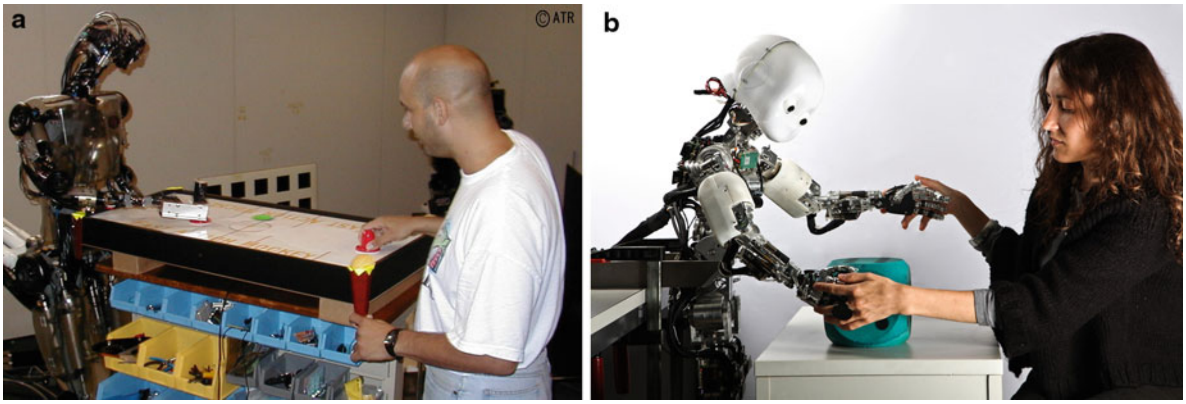
Imitation is the ability to recognize and reproduce others' actions – By extension, imitation learning is a means of learning and developing new skills from observing these skills performed by another agent. Imitation learning (IL) as applied to robots is a technique to reduce the complexity of search spaces for learning. When observing either good or bad examples, one can reduce the search for a possible solution, by either starting the search from the observed good solution (local optima), or conversely, by eliminating from the search space what is known as a bad solution. Imitation learning offers an implicit means of training a machine, such that explicit and tedious programming of a task by a human user can be minimized or eliminated. Imitation learning is thus a "natural" means of training a machine, meant to be accessible to lay people.

Theoretical Background

Like other robot learning paradigms, imitation learning has grown from observations and models of how animals such as rats, monkeys, birds, dolphins, and of course humans acquire and adapt skills via interactions with others. The term itself is drawn from ethology and developmental psychology, where it describes a wide variety of imitative behaviors growing in complexity across species (Breazeal and Scassellati 2002). One distinguishes between simple imitative behavior, also referred to as copying, mimicry, or even social facilitation, which one finds in rats and monkeys, and "true imitation," where the animal can learn behaviors not part of its innate repertoire, and is in the purview of high primates, particularly humans. When used in the context of robot learning, IL also allows for some gradation in the complexity of the behavior that can be learned and the amount of a priori information given to the system. While one body of work is devoted to learning very low-level skills (e.g., encoding skills as joint trajectories, Fig. 1b), other work focuses on learning complex behaviors by sequencing and aggregating built-in behaviors (Fig. 1a) (Billard et al. 2008).

Robot imitation learning was developed to address several difficulties with the standard methods of instantiating robot controllers. Primary is the inability of humans to preprogram a robot for every possible scenario, but secondary concerns include making the robot's behavior appear more "natural," and enabling nonprogrammers to modify robot behavior. The approach itself proceeds with the robot observing performances of a task by the expert (demonstrations), and subsequently developing a control law with the goal of successfully completing the task in novel situations. As intended, this approach to controller creation stands in contrast to explicit programming, where a user must first analyze the task and then explicitly tell (program) the robot how to perform it, but also differs from reinforcement learning, where the user only gives out rewards or punishments and does not indicate what appropriate behavior is. Instead, in IL the analysis of what is important to reproduce (*what to imitate*) and how to reproduce it (*how to imitate*) to achieve the task is done primarily by the robot. This analysis can sometimes be done under close guidance from the teacher, a process to which one refers as incremental learning or tutelage.

At its root, imitation learning seeks to establish a robot control policy that maps a robot's state to actions, or changes to that state. Both state and actions can be external to the robot (perceived by sensors and carried out by actuators) or internal (residing within the robot's "mind"). Demonstrations can arise from many methods, ranging from free-space



Imitation Learning in Robots. Fig. 1 Examples of robots learning via imitation. In (**a**) a robot observes a human demonstrator and combines known motor primitives to play air hockey. In (**b**) a robot is taught kinesthetically and learns the arm trajectory necessary to manipulate the die (Images copyright ATR and LASA)

demonstrations by users that have different embodiments and perceptions (Fig. 1a) to direct actuator teleoperation or kinesthetic manipulation (Fig. 1b). If they are generated externally, then some method of transforming the demonstrations into the robot's frame of reference must be used (Argall et al. 2009). Either way, demonstrations give rise to state-action pairs, indicating that for this particular task, a particular action can be associated with a particular state.

If the demonstrations cover the entire state space (or conversely, the robot were limited to experience only the states that occurred in the demonstration), then robot performance of the task could be as simple as "replaying" the appropriate demonstration, assuming that the robot's memory and computational processes were fast enough to do so. However, in the real world state and action spaces are continuous and possibly infinite, so the necessary data cannot be gathered. Thus, as the goal of imitation learning is to enable the robot to accomplish the task in novel situations, the robot must *generalize* the demonstrations.

Important Scientific Research and Open Questions

Imitation learning for robots is still a young field, and as such there is much debate as to how it should be gone about (Schaal et al. 2003). A few surveys exist that review the work to date (Argall et al. 2009; Billing and Hellstrm 2010; Billard et al. 2008). However, it has emerged that the task of learning by imitation can be further broken down, with each subproblem having its own varied and ongoing research community (Nehaniv et al. 1999):

- Learning *what* to imitate – some portions of the demonstration may be irrelevant for the task.
- Learning *how* to imitate – there may be multiple possible ways to perform or encode the task.
- Learning *when* to imitate – the task can only be attempted in certain circumstances, and the demonstrator may not always be performing the task.

For considering what to imitate, one approach is to take multiple demonstrations (from the same or different users) and compare them. Similarities across the demonstrations are more likely to be associated with the task itself, while differences may be user or example dependent. An alternative is to give a more active role to the users, and enable them to indicate which portions of the demonstration are more important.

Learning how to imitate relates both to the physical actions carried out by the robot, and the underlying encoding (and learning) of the controller. As the expert and learner may have different embodiments, it may be impossible for the robot to perform the task exactly as it was shown. Even if it were possible, it may not be necessary or desirable, as there are often multiple, equally valid methods of attaining a particular goal. The method of representing and encoding the controller affects the robot's behavior as well. For instance, one representation would be to directly encode the mapping from states to actions, so that controlling the robot becomes a function evaluation. Here the robot learns that precise trajectories through state and action space are important. Another approach would be to only determine which portions of the state-action space are desirable, in which case control becomes a path-finding problem. In this view, the robot learns that goals are important, and paths perhaps less so.

Even within these different representations, there are many possible learning methods, and often the same method can be used in different representations. It is in this area that imitation learning draws heavily from the field of machine learning for techniques. Two popular families of approaches are *Neural Networks*, which attempt to simulate how living brains work, and *Statistical Learning*, which uses mathematical models to describe and infer the policy. Each family has a plethora of different flavors, each with their own advantages and disadvantages.

The issue of when to imitate arises when you consider robots that exist over longer timescales, or are capable of performing multiple tasks. While now demonstrations are often collected during dedicated training sessions and applied in explicit test sessions, future always-on robots will have to appropriately identify opportunities to learn, and correct situations to apply the tasks they know.

Research in all of these areas is following multiple avenues simultaneously as the field of imitation learning continues to grow and reshape itself. Some current research examines ways in which imitative learning can be combined with other learning methods, such as reinforcement learning. In that vein, robots first begin learning from imitation, but then can improve their skills by practice and feedback from humans.

Cross-References

- ► Learning Algorithms
- ► Model-Based Imitation Learning
- ► Robot Learning
- ► Robot Learning from Demonstration

References

Argall, B. D., Chernova, S., Veloso, M., & Browning, B. (2009). A survey of robot learning from demonstration. *Robotics and Autonomous Systems*, *57*(5), 469–483.

Billard, A., Calinon, S., Dillmann, R., & Schaal, S. (2008). Robot programming by demonstration. In B. Siciliano & O. Khatib (Eds.), *Handbook of robotics*. Cambridge, MA: MIT Press.

Billing, E. A., & Hellstrm, T. (2010). A formalism for learning from demonstration. *Paladyn*, *1*(1), 1–13.

Breazeal, C., & Scassellati, B. (2002). Robots that imitate humans. *Trends in Cognitive Science*, *6*, 481–487.

Nehaniv, C. L., Ab, H. A., & Dautenhahn, K. (1999). Of hummingbirds and helicopters: An algebraic framework for interdisciplinary studies of imitation and its applications. In J. Demiris & A. Birk (Eds.), *Interdisciplinary approaches to robot learning* (pp. 136–161). Singapore: World Scientific Press.

Schaal, S., Ijspeert, A., & Billard, A. (2003). Computational approaches to motor learning by imitation. *Philosophical Transaction of the Royal Society of London*, *358*(1431), 537–547.

Imitation: Definitions, Evidence, and Mechanisms

Thomas R. Zentall
Department of Psychology, University of Kentucky, Lexington, KY, USA

Synonyms

Copying; Observational learning; Social learning

Definition

Imitation involves the copying of an otherwise improbable response demonstrated by another individual that cannot be attributed to (a) contagion (e.g., flocking, mobbing, yawning, laughing), (b) social facilitation (the mere presence of another), (c) local or stimulus enhancement (attention drawn to a place or object by the sight of a conspecific at that place or interacting with that object), or (d) emulation, learned affordances, or object movement reenactment (learning how the environment works).

Theoretical Background

Social learning, the ability of animals to learn from observing the behavior of others, would appear to have adaptive value because it reduces the likelihood of experiencing the negative consequences of trial and error learning. There are various kinds of social learning, the most theoretically interesting of which is imitation – and especially a form of imitation in which the imitated response by the observer is perceptually opaque to the observer. Perceptually opaque responses are those for which, from the perspective of the organism that produces the behavior, there is little perceptual similarity between this action and the same action when it is performed by another organism (e.g., putting one's hand on one's head). The question is, assuming that the observer is motivated to imitate a demonstrated behavior, how does the observer know when its own behavior matches the behavior of the other? This is the question of correspondence.

Piaget (1962) proposed that the problem of correspondence can be solved in humans if the observer can take the perspective of a third person (i.e., if one could imagine what one looks like to someone else). Thus, if one can find evidence for such imitation in animals other than humans, it would have important implications for possible learning mechanisms. However, before addressing the question of the mechanisms involved in imitation by animals, one first needs to distinguish imitation from other, perhaps simpler, mechanisms that might be responsible for behavioral matching.

Alternatives to Imitation

Contagion. Contagious behavior can be defined as behavior that is automatically triggered, or released, by the similar behavior of others (in humans, yawning and laughing are contagious behaviors). Contagion typically applies to reflexive behavior that occurs in the presence of the performing demonstrator and does not require learning. Researchers who study imitation in animals can generally avoid this reflexive behavioral similarity by using an arbitrary or unlikely target behavior and by asking if the observed behavior will be performed after the demonstrator has been removed from the presence of the observer.

Mere presence. An increase in a target behavior may be attributed to the mere presence of the demonstrator (a phenomenon sometimes referred to as *social facilitation*). If the presence of another animal increases the general arousal of the observer, it may increase the general activity of the observer and in turn indirectly increase the likelihood of the target behavior (e.g., lever pressing, in experiments with rats). Researchers can control for mere presence by including a control condition involving observation of an animal that does not demonstrate the target behavior.

Stimulus enhancement. If the target behavior involves manipulation of an object (e.g., lever pressing), the movement of that object (independent of the behavior of the demonstrator) may be sufficient to draw the observer's attention to it, thus increasing the likelihood that the observer will approach and manipulate the object. This attentional mechanism is often called *stimulus enhancement.* When attention is drawn to a location (e.g., the hole in a fence through which a conspecific can escape) it is referred to as *local enhancement.* Stimulus enhancement and local enhancement pose special procedural challenges if they are to be distinguished from imitation.

Emulation. It is also possible that the sequence of events observed, rather than the method of producing those events, may be the basis for the observer's learning. Observing a performing demonstrator may lead an observer to learn how the environment works (developmental psychologists refer to this as learning the *affordances* of the task, but it has also been referred to as *observational conditioning* or *object movement reenactment*). For example, a young child who is shown the top being removed from a capped pen may be more likely to remove the cap than a control child who is merely shown the pen. However, the child may learn simply that the pen comes apart, and one might see the same increase in cap removal if the child saw the two pieces coming apart without actually seeing someone demonstrate it.

By a process of elimination of factors that do not qualify, we can identify the critical aspects of imitation and a sharper definition emerges: Thus, for an action to qualify as imitation, the observer must learn the specific response topography (i.e., the specific action by which the response is made).

The Two-Action Procedure

The two-action procedure can be used to control for each of the alternatives to imitation that have been described. This procedure involves two experimental groups that differ only in the form or topography of the response demonstrated. The question addressed is whether each observer will tend to use the response topography that it has observed, rather than the alternative response topography observed by other observers. If so, imitation is indicated.

Such evidence for imitation has been reported for both pigeons and Japanese quail observing a conspecific either stepping on a treadle (a flat plate located just above the floor) or pecking at a treadle to obtain reinforcement (see, e.g., Akins and Zentall 1996).

When quail observers that had seen a pecking demonstrator were given access to the treadle, 92% of their responses to the treadle matched those of the demonstrator; among observers that had instead seen a stepping demonstrator, 80% of their responses to the treadle matched those of the demonstrator.

Is the Behavior Perceptually Opaque?

To what extent are pecking at and stepping on a treadle perceptually opaque? Although a bird may be able to see its own beak, the visual stimulus of its own beak while pecking is certainly quite different from the visual stimulus of the demonstrator's beak while it is pecking. Similarly, although at certain times it is possible for a bird to see its own feet, it cannot do so while it is stepping on the treadle because when the bird is in a stepping or walking position, its protruding chest prevents the bird from seeing its feet. Thus, in neither case does the stimulus provided by the sight of a demonstrator pecking or stepping resemble the stimulus provided to the observer by its own pecking or stepping behavior.

Demonstrator Reinforcement

If copying a demonstrated response occurs reflexively, one might expect that the consequences of the demonstrator's behavior (to the demonstrator) would not be an important factor in whether the observer copies the behavior. If, however, imitation involves more cognitive processes (e.g., understanding that consequences of the observed behavior are not of biological importance), observed consequences to the demonstrator might have an effect on the probability that the observer will imitate. We have found that when Japanese quail are given access to a treadle after being exposed to a demonstrator that received food for pecking or stepping on the treadle, most of the observers' responses match those of their demonstrator. However, when the demonstrators receive no food for pecking at or stepping on the treadle, the observers do not imitate the target behavior (Akins and Zentall 1998).

Observer Motivation

In humans, imitation is likely to depend on the motivation of the observer to attend to the behavior of the demonstrator. For example, someone who is interested in learning how to drive a motorcycle is more likely to learn how to do this through imitation than is someone who has no interest in learning how to operate a motorcycle. Might motivation be important to imitation in animals as well? If an animal observes another animal performing a task for which food is the reinforcer, will the observer be more likely to learn about the task if it is hungry than if it is not? In fact, there is evidence that Japanese quail will imitate only if they are hungry during the period of observation (Dorrance and Zentall 2001).

Deferred Imitation

Bandura (1969) proposed that evidence for imitation is more convincing if the period of observation is separated in time from the period during which the observer's performance is assessed. The rationale for this proposition is that deferred imitation would not only rule out the possibility that the observer's response to the behavior of the demonstrator is reflexive, but it would also suggest that the observer must have formed a cognitive representation of the demonstrated behavior that later it could access. With this in mind, we have found that Japanese quail will imitate even when the period of observer performance is deferred by as long as 30 min from the time of observation – a period certainly long enough for the observer's behavior to qualify as deferred imitation (Dorrance and Zentall 2001).

Important Scientific Research and Open Questions

There is now considerable evidence that in addition to humans and the great apes, birds (pigeons and Japanese quail) can imitate perceptually opaque behavior. The behavior appears to be true imitation because it has been demonstrated under conditions that rule out alternative accounts.

Recent research with monkeys has shown that certain neurons that are activated when a monkey performs a grasping action are also activated when the monkey observes a human perform a grasping action. Although the discovery of these specialized *mirror neurons* is exciting, it should be noted that in this case the behavioral correspondence was relatively transparent because there was visual similarity between the grasping action produced by the experimenter and that produced by the monkey itself. A critical question is whether mirror neurons will prove to be responsible for imitation in animals even under more opaque conditions. Even more important is the question of whether these mirror neurons belong to "prewired" neural pathways that evolved to facilitate imitation or have to be trained to behave the way they do. If learning is required, mirror neurons may result from imitation rather than be its cause.

Thus, the major question that remains is, what mechanisms underlie the ability of animals to imitate? As this is not an easily answered question, it may be more functional to ask some more tractable ones. For example, humans are able to imitate a sequence of responses (e.g., how to change batteries in a flashlight). Can animals show such an advanced form of imitation (for suggestive evidence obtained from pigeons, see Nguyen et al. 2005)? Also, why has it been relatively easy to demonstrate imitation in bird species but relatively hard to find evidence for imitation in non-primate mammals? The attempt to answer such questions should help researchers understand this perplexingly complex behavior.

Cross-References

► Imitation and Learning
► Imitative Learning in Humans and Animals
► Observational Learning of Complex Action (Dance)
► Observational Learning: The Sound of Silence
► Social Learning in Animals
► Social Learning Theory

References

Akins, C. K., & Zentall, T. R. (1996). Imitative learning in male Japanese quail (*Coturnix japonica*) using the two- action method. *Journal of Comparative Psychology, 110*, 316–320.

Akins, C. K., & Zentall, T. R. (1998). Imitation in Japanese quail: The role of reinforcement of demonstrator responding. *Psychonomic Bulletin & Review, 5*, 694–697.

Bandura, A. (1969). Social learning theory of identificatory processes. In D. A. Goslin (Ed.), *Handbook of socialization theory and research* (pp. 213–262). Chicago: Rand-McNally.

Dorrance, B. R., & Zentall, T. R. (2001). Imitative learning in Japanese quail depends on the motivational state of the observer at the time of observation. *Journal of Comparative Psychology, 115*, 62–67.

Nguyen, N. H., Klein, E. D., & Zentall, T. R. (2005). Imitation of two-action sequences by pigeons. *Psychonomic Bulletin & Review, 12*, 514–518.

Piaget, J. (1962). *Play, dreams, and imitation in childhood* (Trans: Gallegno, C. & Hodgson, F. M.). New York: Norton.

Imitative Learning

Acquiring a response by observing the response produced by others; considered to involve understanding the relation of one's own behavior to that of others.

Cross-References

► Visual Communication and Learning

Imitative Learning in Humans and Animals

HARRIET OVER, MALINDA CARPENTER
Department of Developmental and Comparative Psychology, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany

Synonyms

Copying; Cultural learning; Observational learning; Social learning

Definition

Imitative learning occurs when an individual acquires a novel action as a result of watching another individual produce it. It can be distinguished from other, lower-level social learning mechanisms such as local enhancement, stimulus enhancement, and contagion (see ► Imitation: Definition, Evidence, and Mechanisms). Most critically within this context, it can also be distinguished from emulation in which an individual learns about the affordances and/or causal properties of the objects involved in a demonstration rather than the particular actions used by the model. In stark contrast to emulation, the term "over-imitation" is sometimes used to refer to action copying that is so faithful that it includes the casually irrelevant and unnecessary actions of a model (technically, however, this term is better reserved for cases in which a learner copies a model's unnecessary actions even when they have been explicitly instructed not to do so).

Theoretical Background

Human culture is qualitatively different from that of any other species. The depth and breadth of our cultural traditions dwarf those of even our closest living primate relatives, chimpanzees. Researchers have thus far documented a total of a few dozen cultural differences between different chimpanzee groups (Whiten et al. 2001). Humans clearly go far beyond this: the cultural variation between human groups is practically limitless, from differences in the ways in which we speak, eat and dress, to differences in the cultural rituals we engage in. Learning how group members in general tend to do things is thus extremely important for human cultural transmission. Copying group members' actions is consequently much more important for us than it is for chimpanzees.

Empirical research has shown that a major difference between social learning in humans and chimpanzees is that, whereas chimpanzees tend to copy outcomes (that is, emulate), humans tend to copy actions, and do so from early in development. Many studies, from many different labs, have shown that young children typically copy the actions others demonstrate faithfully. They do this even when the model's actions are clearly unnecessary or causally irrelevant, when it results in less efficient performance on their part, and, on occasion, even when they are explicitly told not to. In contrast to the behavior of young children, chimpanzees spontaneously copy others' actions only rarely.

Beyond copying actions versus outcomes, there are several other, even more deeply social aspects of imitation that appear to be unique to humans. As we will see below, these all involve the motivation to be like other members of the group, and the pressures, coming both from within individuals and from the group itself, to do things the way "we" all do them. When compared to social learning in chimpanzees (as well as to social learning in other animal species), it is clear that imitative learning in humans is a profoundly social process.

Important Scientific Research and Open Questions

As outlined above, the key differences between imitative learning in humans and animals appear to reside in the social motivations and social pressures which influence human copying behavior. One situation in which the social pressure to imitate is particularly clear is teaching. When engaged in a teaching situation, knowledgeable members of the group often mark information that is important for the learner to reproduce with social cues such as ostensive eye contact. Recent research has shown that even infants are sensitive to these teaching cues and motivated to respond to them. Gergely and Csibra (2006), for example, report an experiment in which 14-month-olds infants were presented with a demonstration in which a model performed an unusual action: turning on a light box using her head rather than her hand. In one condition, the model indicated that this information was important for the infants by marking it with ostensive eye contact. In the other condition, the model did not provide any teaching cues. Results showed that infants were significantly more likely to copy the unusual action when it was accompanied by ostensive eye contact.

Further research has shown that children do not merely experience social motivation and pressure to imitate on a dyadic level (as in many teaching situations) but also do so on a group level. This group-level aspect of imitation is evident in normativity. When a knowledgeable group member demonstrates an action for a child, the child often learns it normatively, as the way group members in general ought to behave. In one of the earliest illustrations of this, Rakoczy et al. (2008) presented 3-year-old children with demonstrations of how to play a novel game. Once children had learned the game, a puppet asked to join in but then performed the relevant actions incorrectly. Children protested against this violation of the norms of the game, attempting to enforce the learned norms on the puppet. The children in this study thus demonstrated that they had internalized the relevant norms and expected other group members to adhere to them as well.

Another area in which the group-level aspects of imitation are particularly clear is conformity. In adults at least, conformity is a powerful mechanism through which cultural norms, behaviors, and attitudes are learned and maintained. Recent research has shown that young children also conform to the behavior of those around them. In fact, the motivation and pressure to conform is so great that children conform to the claims of their group members even when those claims are clearly false. For example, when presented with an Asch-style test of conformity, 4-year-olds conform to the majority's opinion on almost 40% of trials (Haun and Tomasello in press). Evidence that social motivations and pressures underlie much of children's "extreme" copying come from findings like the following: children conform more in public than in private (Haun and Tomasello in press) and increase how closely they copy others when they have a goal to affiliate (Over and Carpenter 2009).

In contrast to human children, there is little evidence that chimpanzees experience either social motivation or social pressure to imitate. For example, chimpanzees do not appear to be sensitive to either social-teaching cues, such as ostensive eye contact, or to social norms. Recently, however, there has been some suggestion that chimpanzees show conformity to the behavior of their group members. That is, when individual chimpanzees are trained how to use a particular technique in order to obtain food and then placed back into their social group, the learned technique tends to spread to other group members (Whiten et al. 2005). However, this is most likely a product of lower-level social learning mechanisms such as emulation, rather than (internally or externally felt) social pressure to conform to the behavior of group members.

Open questions, of course, remain. In terms of developmental research, one of the most pressing questions for future research is the extent to which the intergroup context influences imitation. For example, do young children learn actions more readily and more deeply from ingroup members than from outgroup members? In terms of comparative research, one open question relates to enculturation. Previous research has suggested that extensive human contact increases chimpanzees' tendency to copy actions. Does this process of enculturation increase the social motivations and pressures chimpanzees feel to imitate? Other open questions relate to imitative learning in other animal species. Previous research has shown that a great many animal species including, but not limited to, rats, songbirds, dolphins, and whales are capable of social learning (see *Social learning in animals*). To what extent (if at all) does the social context influence copying in these other animal species?

Cross-References

- ► Animal Culture
- ► Imitation and Social Learning
- ► Imitational Learning of Robots
- ► Learning and Evolution of Social Norms
- ► Model-Based Imitation Learning
- ► Social-Cultural Learning
- ► Social Learning in Animals

References

Gergely, G., & Csibra, G. (2006). Sylvia's recipe: The role of imitation and pedagogy in the transmission of human culture. In N. J. Enfield & S. C. Levinson (Eds.), *Roots of human sociality: Culture, cognition, and human interaction* (pp. 229–255). Oxford: Berg Publishers.

Haun, D. B. M., & Tomasello, M. (in press). Conformity to peer pressure in preschool children. *Child Development.*

Over, H., & Carpenter, M. (2009). Priming third-party ostracism increases affiliative imitation in children. *Developmental Science, 12*, F1–F8.

Rakoczy, H., Warneken, F., & Tomasello, M. (2008). The sources of normativity: Young children's awareness of the normative structure of games. *Developmental Psychology, 44*, 875–881.

Whiten, A., Goodall, J., McGrew, W. C., Nishida, T., Reynolds, V., Sugiyama, Y., Tutin, C. E. G., Wrangham, R. W., & Boesch, C. (2001). Charting cultural variation in chimpanzees. *Behaviour, 138*, 1489–1525.

Whiten, A., Horner, V., & de Waal, F. B. M. (2005). Conformity to cultural norms of tool use in chimpanzees. *Nature, 437*, 737–740.

I

Immediate Memory

► Working Memory and Information Processing

Immigrant Learning

► Learning and Education in Migration Settings

Impaired Multidimensional Motor Sequence Learning

Michael Borich, Lara Boyd
University of British Columbia, Vancouver, BC, Canada

Synonyms

Categorization of variation in movement; Dimension of movement; Domain of movement; Elements of movement

Definition

Inability to learn a dimension of movement with practice in response to specific task demands during a motor task requiring serial, patterned movement. The three primary dimensions are: (1) motor (movement command), (2) spatial (movement in space), and (3) temporal (timing of a movement).

Theoretical Background

Learning motor skills involves integrating many elements of a movement in an environment in order to successfully perform the desired response consistently over time. Most "real-life" skills involve sequential movements to complete a task. In a controlled laboratory setting, these elements are usually tested in isolation making it difficult to deduce which elements are most salient to acquisition of a given skill. Every movement dimension (motor, spatial, and temporal) requires a certain level of precision for successful skill production. For example, to place an object on a table, an outgoing motor command is adapted to account for location of the table, spatial adjustments are made for proper placement of the object on the table, and temporal modifications allow for release of the object once it reaches the table surface. Although each dimension is learned as an integrated unit, the importance of one dimension over another for a skill to be acquired is largely unknown. It is also remains unclear how multidimensional motor skill learning changes across the lifespan or following neurologic injury.

Important Scientific Research and Open Questions

Previous research has largely focused on short-term performance changes for unidimensional sequence skill acquisition. Impairments in sequence skill learning have sometimes been observed with normal aging (Curran 1997), but not always (Frensch 1994). Impaired sequence learning is commonly noted following neurologic injury (Boyd and Winstein 2001). Motor skills range from sequencing spoken words, spatial sequencing, nonspatial visual letter sequencing, and visuomotor sequencing. Discrepancies in the literature may be the result of the type of skill studied, task difficulty, outcome measures used, and/or lack of delayed retention testing. Additionally, it is less common for the individual and/or combined contributions of the primary dimensions of movement to be investigated (Boyd et al. 2008).

Visuomotor sequence learning is commonly examined using the serial reaction time task (SRTT) paradigm. The SRTT involves a response to repeated, patterned stimuli by pressing a key corresponding to a presented visual cue (Nissen and Bullemer 1987). Under these conditions, the motor dimension of movement is primarily examined without specifically characterizing the spatial or temporal aspects of the movement. Skill performance is assessed by accuracy of response and response time (reaction time+ movement time) for a repeated sequence of stimuli compared to a random stimuli sequence (Nissen and Bullemer 1987). Recently, Boyd and colleagues (Boyd et al. 2008) investigated the relationship between dimensions of movement using an adapted SRTT learning paradigm. The authors adapted this task to isolate each movement dimension to determine the role of each dimension in sequential skill acquisition across the human lifespan. Results indicated that young (23–35 years) and middle-aged (38–64 years) healthy individuals demonstrate sequence-specific learning that is sensitive to the motor pattern. In contrast, older (71–83 years) adults demonstrate nonspecific skill learning (improvement in both repeated and random sequence performance) that does not appear to be specific to one dimension of movement. The authors concluded that the observed differences in motor learning across the lifespan may be due to an inability to utilize the repeated multidimensional information during practice to improve performance. They also hypothesize that this multidimensional learning deficit may have a substantial impact on rehabilitation strategies following neurologic injury.

To date, the importance of specific dimensions of movement on skill (re)learning following neurologic injury is unknown. Using the adapted SRTT in patient populations may help identify the relative importance of each element of movement to refine rehabilitation strategies targeted at restoring function. These data will also assist in distinguishing normal changes in learning capacity from changes resulting from neurologic injury. Additionally, neuroimaging should be incorporated to determine the neural substrates of multidimensional motor sequence learning in healthy and patient populations. A comprehensive understanding of the neurobehavioral physiology in both healthy individuals across the lifespan and individuals after neurologic injury has yet to be attained but technological advancements, foundational experiments, and novel research methodologies provide numerous future directions to meet this goal.

Cross-References

- ▶ Aging Effect on Motor Learning
- ▶ Explicit Versus Implicit Learning
- ▶ Implicit Sequence Learning
- ▶ Memory Consolidation and Reconsolidation
- ▶ Motor Learning
- ▶ Multimodal Learning
- ▶ Procedural Learning
- ▶ Sequential Learning
- ▶ Spatial Learning
- ▶ Task Sequencing and Learning
- ▶ Temporal Learning

References

Boyd, L. A., & Winstein, C. J. (2001). Implicit motor-sequence learning in humans following unilateral stroke: The impact of practice and explicit knowledge. *Neuroscience Letters, 298*(1), 65–69.

Boyd, L. A., Vidoni, E. D., & Siengsukon, C. F. (2008). Multidimensional motor sequence learning is impaired in older but not younger or middle-aged adults. *Physical Therapy, 88*(3), 351–362.

Curran, T. (1997). Effects of aging on implicit sequence learning: Accounting for sequence structure and explicit knowledge. *Psychological Research, 60*(1–2), 24–41.

Frensch, P. A. (1994). Composition during serial learning: A serial position effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(2), 423–442.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*, 1–3.

Impaired Verbal Associative Learning

Michael Martin Saling
Department of Psychological Sciences, The University of Melbourne, Melbourne, Victoria, Australia

Synonyms

Impaired verbal conjunctive learning; Impaired verbal relational learning

Definition

Impaired verbal associative learning is a compound term referring to disturbances in a learning process whereby conjunctions are formed between co-occurring linguistic entities, ranging from the phonemic, through lexical, to propositional levels of language. An impairment is disturbance that is attributable to disease or injury in an organ system, in this context the brain. Verbal association falls under the general class of ▶ associative learning processes that involve the formation of conjunctions between percepts, behaviors, and concepts. At its simplest level, association approximates the idea of perceptual binding, in which fundamental sensory and perceptual attributes of an object are linked to form a unified representation. At a more complex level, preestablished representations such as words, objects, concepts, propositions, personally experienced events, and dimensions such as time and space are conjoined to form the basis of episodic and semantic memories. There are no strict bounds to the definition of verbal associative learning, and because of its importance in the emergence of the referential aspects of language, conjunctions in which only one of the items is linguistic (such as word object pairs) are appropriately subsumed under this rubric.

Verbal associative learning is conventionally studied by asking a person to learn lists of word pairs. The task requirement is the acquisition of relational information, in contrast to item or nonassociative learning where relational information is not relevant to the task. The nature of the relational information has a determing influence on its cerebral representation, and ultimately the manner in which associative learning is impaired by brain disorders. In verbal associative paradigms, the nature of the relational content can be defined explicitly, and therefore experimentally manipulated, in linguistic terms. A conjunction can be considered to be "structured" or "related" if the relational content is preestablished. A word pair such as CAT-DOG would fall into this category as exemplars of the superordinate category of household animals, but the preestablished relational information could be built on semantosyntactic structures such as noun–verb predication (KITE-FLIES), catgory-exemplar pairings (ANIMAL-LION), antonymy (LIGHT–DARK), and so on. Alternatively, a conjunction might have a very low or zero probability of prior representation, in which case it can be considered to be "unstructured," "arbitrary," or "unrelated" (DESK-BICYCLE or CABBAGE-PEN). Impairments in verbal associative learning affect the relational component of the task, not the learning of single, unassociated items. Arbitrary and semantic forms of verbal associative learning are dependent on different systems in the brain, and are therefore differentially impaired by focal brain damage.

Theoretical Background

Associative learning is fundamentally dependent on parts of the brain that are, by virtue of their neural architecture, specialized for conjunctive processing. Principal amongst these are structures located deep within the temporal lobe, the hippocampus and parahippocampal region (which together constitute the hippocampal system). The hippocampus has been referred to as the "highest form of association cortex" by the neuroanatomist Pierre Gloor, in recognition of the fact that it receives inputs from all other association cortices in the brain. This, together with the convergent and recurrent nature of its neuronal networks, enables it to form associations between items from different cognitive and behavioral domains, such as perception and action, and to represent links between items previously stored in different cortical loci. One of the most influential theories of verbal and nonverbal learning impairments after hippocampal damage is the notion of material-specificity. This model owes much to the pioneering work of Brenda Milner and her colleagues at the Montreal Neurological Institute. It holds that the left and right temporal lobes process different *types* of material (Milner 1970), that is, "a complementary specialization of the two temporal lobes of man with respect to memory…the most significant variable is the verbal or nonverbal character of the material to be retained" (pp. 29–30).

The material-specificity model implicitly embodies a specific stance toward the structure of verbal and nonverbal memory, and their distribution between the left and right hemispheres of the brain: (1) Verbal and nonverbal memory are unitary and internally homogenous constructs. This assumption is reflected in the wide range of verbal tasks, from single word (nonassociative) paradigms to linguistically complex discourse, that have been used interchangeably, or in summation, to characterize putatively verbal-specific impairments. (2) The left temporal-verbal memory system mediates all aspects of verbal memory but does not deal with nonverbal memory, and vice versa for the right temporal memory system. In other words, the two lateralized memory systems are assumed to be independent self-contained modules. There is now a substantial body of research that does not support this assumption.

During the late 1980s and early 1990s, the view began to emerge that the "verbal … character of the material to be retained" is not a sufficient condition for exclusive representation in the left hippocampal system. Rather, it is the cognitive architecture of the verbal learning paradigm that recruits greater left than right hippocampal involvement. Cell loss in the left hippocampal system predicts impaired learning of arbitrary or unstructured verbal paired associates, but not in paradigms, ranging from structured verbal-paired associates to connected propositional language, where the relational content has prior representation in semantic memory and, therefore, has the benefit of top-down semantic facilitation effects. For tasks in which performance is supported by preestablished semantic associations, the effect of left hippocampal damage on learning ability is minimal or absent. Since the material-specificity model in its theoretical stance and in its clinical implementation emphasizes the verbal versus nonverbal nature of material to be learned, to the exclusion of any other attribute of the task, it cannot accommodate the phenomenon of lesion-induced dissociation (such as selective impairments in arbitrary versus semantic forms of learning).

In his seminal work on "Organization of Behavior," D.O. Hebb (1949) noted that "as to the wide range of difficulty of associating two ideas or perceptions, even for the adult, this is psychologically a matter of common experience… The fact of unequal difficulty of associations is not stressed in the literature … but it is a fact" (p. 78). That related verbal pairs are easier to learn than unrelated verbal pairs is a robust finding in the older verbal learning literature, but its significance for models of verbal associative learning and its impairment has only emerged in recent years. It has now become clear that left hippocampal damage exerts a primary influence on a neurocognitive system responsible for the rapid and obligatory uptake of verbal co-occurences that have yet to be established in personal episodic or semantic memory, or which are potentially incompatible with preestablished knowledge. This process is fundamental to ► autonoesis since the acculumated conjunctive representations signpost behavioral trajectories over time, providing a temporary and consciously accessible record, irrespective of the arbitrariness or ultimate significance of its content (Moscovitch 2008). While this property is phylogenetically ancient, providing a buffer against the speed and unpredictability of environmental events (McClelland and Goddard 1996), its instantiation in the left hippocampal region is capable of mediating a ► protosemantic form of learning, leading eventually to new verbal knowledge. This, in turn, presupposes that unique relational information can be protected against interference by overlapping representations, despite its arbitrariness. A theoretical solution to this issue was proposed by O'Reilly and Rudy (2001). Based on the bias of the hippocampal system toward ► sparse processing, overlapping input patterns can be represented at a hippocampal level by unique and discrete ensembles of neuronal activity. This results in ► pattern separation across a myriad of arbitrarily contiguous inputs, enabling rapid uptake without interference. Computational modeling suggests that in contrast to the hippocampus, the neocortex extracts semantic relational regularities from multiple instances, gradually incorporating these into existing semantic networks (McClelland and Goddard 1996).

Important Scientific Research and Open Questions

The differential effects of hippocampal-system damage on verbal relational content is consistent with a number of theories of hippocampal function that assign to it the task of rapid and obligatory uptake of arbitrary conjunctions and that regard this role as fundamental to declarative memory. Models proposed by Howard Eichenbaum, Morris Moscovitch, McClelland and Goddard, and O'Reilly, and Rudy fall into this category. Since the difference between verbal tasks affected and those that escape impairment can be drawn broadly along semanticosyntactic lines, the question of semantic gating in transactions between neocortical association cortices and the hippocampal system is raised. A model advanced by Fernandez and Tendolkar (2006), for example, imbues the ► rhinal cortex, a gateway through which inputs to the hippocampus must pass, with a "gatekeeper" role in declarative memory, and postulates that this gating function is modulated by the semantic conceptual status of incoming information. Items with no prior representation in semantic memory recruit rhinal activity, thereby increasing the probability of transfer to the hippocampus for encoding. The model postulates further that this neurophysiological change in the rhinal cortex unleashes a subjective feeling of unfamiliarity. On the other hand, rhinal activity is said to be reduced in the face of items with a preestablished semantic representation, reducing the probability of transfer to the hippocampus and inducing a subjective sense of familiarity. The involvement of an arbitrary-meaningful dimension in associative learning at the neocortical-hippocampal interface raises the question of a possible mapping between degrees of semantic structure in associative learning and the familiarity versus recollection distinction in cognitive psychology.

Degrees of impairment in verbal associative learning map onto different regions of the temporal lobe. Impairment in arbitrary forms of verbal associative learning are predicted by dysfunction in structures of the left anterior parahippocampal region. On the other hand, impairments in semantically structured learning are predicted by dysfunction in anterior neocortcal association cortex of the left temporal lobe, reinforcing the neurobiological reality of the relational differences between the two associative tasks. On balance, the uptake of arbitrary verbal associations appears to be well lateralized to the left hippocampal system. The cerebral representation of related verbal associations is likely to be more extensive, and possibly bilateral. If this is the case, it would provide an explanation for the vulnerability of arbitrary forms of verbal associative learning to impairment in disorders, such as Mesial Temporal Lobe Epilepsy and Alzheimer's Disease, that impinge at onset on the hippocampal system. Semantically structured associations are more robust in the face of focal brain disease, except in the case of the Semantic Variant of Frontotemporal Dementia, which begins with atrophy in the left anterior temporal neocortex, causing a profound dissolution of semantic linkages. Given the anatomical proximity of these regions, the anterior temporal region might be a hub of transaction between arbitrary and semantic processing in verbal associative.

Cross-References

► Associationism
► Relational Learning
► Role of Similarity in Human Associative Learning
► Verbal Behavior and Learning
► Verbal Learning

References

Fernandez, G., & Tendolkar, I. (2006). The rhinal cortex: gatekeeper of the declarative memory system. *Trends in Cognitive Sciences, 10*, 358–362.

Hebb, D. O. (1949). *Organization of behavior.* New York: Wiley.

McClelland, J. L., & Goddard, N. H. (1996). Considerations arising from a complementary learning systems perspective on hippocampus and neocortex. *Hippocampus, 6*, 654–665.

Milner, B. (1970). Memory and the medial temporal regions of the brain. In K. H. Pribram & D. E. Broadbent (Eds.), *Biology of memory.* New York: Academic.

Moscovitch, M. (2008). The hippocampus as a "stupid," domain-specific module: Implications for theories of recent and remote memory, and of imagination. *Canadian Journal of Experimental Psychology, 62*, 62–79.

O'Reilly, R. C., & Rudy, J. W. (2001). Conjunctive representations in learning and memory: Principles of cortical and hippocampal function. *Psychological Review, 108*, 311–345.

Impaired Verbal Conjunctive Learning

► Impaired Verbal Associative Learning

Impaired Verbal Relational Learning

► Impaired Verbal Associative Learning

Impairment

A disturbance in a function attributable to a pathological state in an organ of the body, such as the brain.

Implicit Causal Map of Environmental Problem Situations

► Mental Models of Environmental Problems

Implicit Elaboration

► Consciousness and Emotion: Attentive vs. Pre-attentive Elaboration of Face Processing

Implicit Knowledge

► Tacit Knowledge

Implicit Learning

► Explicit and Procedural-Learning-Based Systems of Perceptual Category Learning
► Learning as a Side Effect
► Procedural Learning
► Unconscious and Conscious Learning
► Unconscious Learning

Implicit Memory

► New Learning in Dementia
► Priming, Response Learning, and Repetition Suppression

Implicit Sequence Learning

Beat Meier, Josephine Cock
Department of Psychology, University of Bern,
Bern, Switzerland

Synonyms

Incidental sequence learning; Procedural learning; Sequence learning without awareness

Definition

Implicit learning refers to a form of learning in which people become sensitive to regularities in the environment without intention and awareness. The core characteristics are the incidental nature of the acquisition process, the lack of intention to learn, and the difficulty of expressing resultant knowledge. The term “implicit learning” was introduced by Reber (1967) in a seminal paper on artificial grammar learning, and the topic of “implicit sequence learning” became an evolving research field in the 1980s with the introduction of the serial reaction time task (SRTT) by Nissen and Bullemer (1987). In fact, artificial grammar learning and sequence learning are still the main paradigms for studying implicit learning. *Implicit sequence learning* (ISL) underlies abilities such as being able to perceive patterns of speech and grammar, or to respond to hidden rules of social behavior. It can be contrasted with *explicit sequence learning*, as in following a recipe or learning to tie one’s shoelaces with guidance. Whereas explicit knowledge enables a person to gain from their experience in a conscious and communicative way, implicit knowledge is detected only indirectly, through changes in performance. The implicit versus explicit distinction is often used synonymously with the procedural (or non-declarative) versus declarative distinction (Cohen and Squire 1980).

Theoretical Background

In the classical SRTT paradigm, participants perform a choice reaction time task in which consecutive stimuli appear at one of four locations horizontally aligned across the center of a computer monitor. A sequence of correct response-key presses follows the sequence of designated target locations and – unbeknownst to participants – the order of the target locations follows a sequence predetermined by the experimenter. With practice, performance gets faster compared to a randomized control condition. If the sequence is switched to random, performance is slowed again. These changes are taken as evidence of implicit sequence learning provided they are not accompanied by explicit knowledge about the sequence elements. Explicit sequence learning is assessed by post-experiment interviews and tests involving sequence reproduction, recall, recognition, or fragment generation. There is ample evidence that participants can acquire knowledge they cannot fully verbalize. However, verbal reports have been criticized as having poor validity. Specifically, the information assessed may not be the same information that has led to learning (i.e., the information criterion) and the measures may not be sensitive enough to pick up all the relevant information (i.e., the sensitivity criterion; Shanks and St. John 1994). It is evident that a considerable number of participants do develop awareness of the existence of a sequence even though they cannot reproduce the particular order of the sequence elements.

In order to reduce the likelihood of participants becoming aware of a particular sequence and to make the task requirements closer to the real world, in which relevant stimuli are mostly filtered from irrelevant background noise, several variations of the classical SRTT have been introduced. For example, rather than presenting a *deterministic* sequence, a *probabilistic* sequence can be used, in which the regular order of stimuli always contains a small percentage of irregular random items. In addition, the temporal distance between the distinctive (to be related) sequence elements can be varied. Second-order transitions, in which the two previous elements are predictive for the following sequence element, are most often used. However, even third-order information can be learned with more training. In an attempt to test the limits of the sequence acquisition mechanism, Cleeremans and McClelland (1991) found that with extensive practice participants gradually acquired third-order sequence information without accompanying verbalizable knowledge. However, even 60,000 trials were not sufficient to learn a fourth-order dependency rule. Therefore, higher-order dependency rules seem to be much harder, or even impossible to learn.

In an early phase of research there was great enthusiasm about the potential power of the implicit learning mechanism. In fact, the idea was that even abstract knowledge, such as rules, can be extracted automatically and unintentionally from any stimuli present in the environment. However, the idea of a “smart unconscious” did not stand up to systematic empirical testing. It emerged that the acquired knowledge consisted rather of surface characteristics that were correlated with elements present in the experimenters’ superimposed abstract rules such as short fragments or chunks. The present, less enthusiastic, view is that implicit sequence learning is based on an associative learning mechanism which is sensitive to statistical dependencies. As a result, the acquired knowledge is probably highly specific, not abstract in nature, and not easily transferable to new situations.

Important Scientific Research and Open Questions

Implicit sequence learning has been described by some researchers as a form of perceptuo-motor priming, similar to procedural learning or skill acquisition, as in expert typewriting or driving. Others see it as primarily response-based, although some studies appear to show "pure" perceptual sequence learning without any involvement of motor responses. These explanations remain hard to reconcile. One possibility, that has been largely dismissed, is that of implicit sequence learning depending entirely on specific finger-related movements.

Although there has been considerable research on the role of attention in implicit sequence learning, the extent to which it is involved is not yet clear. A number of studies have asked whether implicit sequence learning is affected by a concurrent secondary task, typically an unrelated tone-counting task that might have an adverse effect on performance and sequence learning. With this arrangement, participants must memorize the number of tones experienced so far and they must also classify each tone as high or low. When these components are taken apart, it is generally found that implicit sequence learning is unaffected by the secondary task. Presumably this is because the additional information and requirement does not change the way the sequence of the SRTT is processed. However, sequence learning has been found to be affected by an additional motor task, in which a foot pedal had to be pressed in response to high-pitched, but not low-pitched tones. Overall, the general consensus is that ISL is robust even when attentional resources are constrained. However, attention at the level of separate stimulus–response trials appears to be necessary, and ISL may be impaired if attentional requirements of a secondary task interfere with processing of the main sequence. In this regard, symbol counting, mental arithmetic, and articulation have all been found to affect sequence learning adversely under certain circumstances. Furthermore, even if participants successfully combine two tasks, and if they show ISL as well, it still does not mean that learning to perform those tasks does not require attention. In other words, it is difficult to separate out the role of attention vis-à-vis learning, performance, and processing. As the attentional independence of implicit sequence learning has not been satisfactorily established, the question remains under lively debate.

Another issue that remains to be settled concerns the neural architecture of implicit (and explicit) sequence learning. Functional imaging and lesion studies suggest that both cortical and subcortical structures are involved in the SRTT and early research has shown that amnesic patients with lesions to the medio-temporal lobes (MTL) still become sensitive to the structural regularities in classical SRTT experiments. This result has led to the conclusion that implicit sequence learning is independent of the MTL structures, in particular the hippocampus. However, later research, using more complex sequences, has revealed that amnesics' performance and sequence learning is impaired after all. Studies using imaging techniques have also revealed MTL activation in conjunction with ISL in the normal population. It is possible that even within the domain of implicit sequence learning different neural systems are involved depending on the task requirements and the attentional resources that are available. Keele et al. (2003) proposed a cognitive and neural architecture with two separate and competing sequence learning systems, a ventral circuit involving temporal and lateral prefrontal cortex structures and a dorsal circuit involving primarily the parietal and supplementary motor cortex. The ventral system was thought to be used for both implicit and explicit learning, to be "multidimensional," with access to networks of information across diverse regions of the brain including higher cognition and to be mainly involved when the SRTT is performed without a secondary task. In contrast, the dorsal circuit was thought to be used for implicit but not explicit sequence learning. It was said to be "unidimensional," extracting regularities from only one channel of information at a time and involved in situations where sequence learning information must be kept separate from the distracting influence of a secondary task. Standard ISL experimental results can be easily accommodated within Keele et al.'s multidimensional ventral circuit system, as there is always more than one stream of correlated information present, for example, the stream of stimulus locations, the isomorphic spatial arrangement of response keys and the corresponding order in which the keys are pressed. Identifying situations in which only the unidimensional, dorsal circuit system can operate are harder to establish. While from a neuropsychological point of view there seems to be a consensus that multiple systems are involved in sequence learning, results from computational studies stand in sharp contrast to this claim. Most of them suggest that the apparent dissociations between implicit and explicit learning can easily be accounted for by a single system model.

Finally, although the role of implicit sequence learning is recognized in several areas of knowledge acquisition, its practical application has not been extensively tested. The sparse evidence suggests that incidental presentation of learning materials is sufficient for the acquisition of some kinds of knowledge. However, when compared to studying under intentional conditions, typically a strong advantage for explicit instruction is evident. In real-world situations, interaction between incidental and intentional learning may be the norm but so far this interaction has not been under investigation. The question of how implicit and explicit sequence learning can be most successfully combined in real-world situations may become an important avenue of future research.

Cross-References

► Associative Learning
► Attention and Implicit Learning
► Implicit Sequence Learning
► Incidental Learning
► Sequence Learning
► Task Sequencing and Learning

References

Cleeremans, A., & McClelland, J. L. (1991). Learning the structure of event sequences. *Journal of Experimental Psychology. General, 120*, 235–253.

Cohen, N. J., & Squire, L. R. (1980). Preserved learning and retention of pattern analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science, 210*, 207–209.

Keele, S., Ivry, R., Mayr, U., Hazeltine, E., & Heuer, H. (2003). The cognitive and neural architecture of sequence representation. *Psychological Review, 110*, 316–339.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*, 1–32.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6*, 855–863.

Shanks, D. R., & St. John, M. F. (1994). Characteristics of dissociable human learning systems. *The Behavioral and Brain Sciences, 17*, 367–447.

Implicit/Explicit Scaffolds

► Scaffolding for Learning

Impulse

► Academic Motivation

Impulse Control

► Impulsivity and Reversal Learning

Impulsive Cueing

► "Clever Hans": Involuntary and Unconscious Cueing

Impulsivity

► Attention Deficit Hyperactivity Disorder

Impulsivity and Reversal Learning

Matthew J. Gullo
Institute of Psychology, Health and Society, University of Liverpool, Eleanor Rathbone Building, Liverpool, UK

Synonyms

Adaptive learning; Behavioral flexibility; Disinhibition; Impulse control; Perseveration

Definition

Impulsivity is the propensity to engage in behaviors without adequate forethought. These behaviors are typically *approach* behaviors aimed at acquiring some kind of reward (e.g., food and money). All major models of human personality include a trait reflecting this propensity, suggesting it to be a core attribute along which people vary. Reversal learning is the updating of stimulus-reinforcement associations when contingencies change. For example, an individual may find foods high in sugar (stimulus) highly pleasurable to eat (reinforcement) and therefore regularly engages in consuming such foods. However, after being diagnosed with diabetes mellitus, they learn to update this association such that high-sugar foods are now linked to serious negative health consequences.

Theoretical Background

Greater understanding of the role of reversal learning in human impulsivity came through observations of patients who had suffered a frontal head injury, especially injuries involving the orbitofrontal cortex. The orbitofrontal cortex is the area of the frontal lobes located above the eye sockets. Harlow (1868) provided one of the first detailed accounts of injury to this brain region suffered by Phineas Gage, a railway worker who had a tampering iron lodged into his skull after an explosive charge detonated unexpectedly on a construction site. Clinical observations of Gage, and other patients with injuries to the orbitofrontal cortex, revealed an inability to "unlearn" associations between actions and outcome (i.e., reversal learning deficits). For example, a patient might be asked to complete a task where they had learned that selecting a particular card, such as one with a blue square on it, resulted in a reward of some kind (e.g., points or pretend money). However, any other card selections were punished (e.g., loss of points/pretend money). Then, half way through the task the outcomes were switched such that selecting the blue square cards resulted in punishment and selection of any other card resulted in reward. While most healthy individuals can adapt to this contingency shift and "unlearn" the old association after making a few errors, patients with orbitofrontal damage take much longer to do so, if at all. This deficit is thought to underlie the broader social difficulties these patients often experience, as it leads to impulsive behavior, and an inability to adapt to changing circumstances. Subsequent research with healthy individuals using neuroimaging techniques such as functional magnetic resonance imaging (fMRI) have confirmed the importance of the orbitofrontal cortex to successful reversal learning (Cools et al. 2002).

A high level of impulsivity in the absence of any head injury also characterizes a range of psychiatric conditions. Sufferers of drug addiction, pathological gambling, and eating disorders such as bulimia nervosa all have in common the propensity to act on impulses without consideration of future negative consequences, or an inability for such consequences to inhibit the impulses. As a result, impulsivity has been the focus of much research in clinical psychology and psychiatry. Interestingly, these conditions typically involve approach to stimuli that are initially rewarding but, because of excessive use, come to also result in serious negative consequences that outweigh the value of the initial reward. Despite this, individuals suffering such conditions find it very difficult to inhibit their impulse to inject, gamble, or binge. That is, such conditions can be viewed as involving deficits in reversal learning. In addition to this, disruptions in orbitofrontal cortex function have been implicated in these and other disorders of impulse control.

Important Scientific Research and Open Questions

Only more recently has psychological research begun to investigate more integrative models of reversal learning, impulsivity, and psychiatric disorders of impulse control. Such broader focus has come through decades of animal research into fundamental aspects of inhibitory control (Gray and McNaughton 2000), as well as better understanding of the neural underpinnings of behavior, both normal and abnormal, thanks to neuroimaging. From this research has emerged an understanding of psychiatric disorder as lying on the end of a continuum of normal human behavior, and normal human behavior/personality as resulting from the combination of specific neuropsychological processes such as reversal learning, which themselves depend on the integrity of brain regions such as the orbitofrontal cortex (e.g., Gullo and Dawe 2008). For example, deficiencies in the functioning of the orbitofrontal cortex could lead to slowed reversal learning (Cools et al. 2002; Fellows and Farah 2003). This slowing may then manifest more globally in the individual as impulsivity (Gullo et al. 2010) that results in difficulty stopping behaviors like substance use that, while initially were rewarding, are now causing serious health/legal/social consequences (Hildebrandt et al. 2008).

While there is evidence linking these processes together, this is clearly not the whole picture. Reversal learning is only one component underlying impulsivity, which itself is only one of several factors contributing to psychiatric conditions like pathological gambling. Future research is needed to determine not only what other processes are involved but, more importantly, how they affect the role played by reversal learning.

Cross-References

► Neural Mechanisms of Extinction and Retrieval
► Neurophysiology of Motivated Learning
► Personality Effects on Learning

References

Cools, R., Clark, L., Owen, A. M., & Robbins, T. W. (2002). Defining the neural mechanisms of probabilistic reversal learning using event-related functional magnetic resonance imaging. *The Journal of Neuroscience, 22*, 4563–4567.

Fellows, L. K., & Farah, M. J. (2003). Ventromedial frontal cortex mediates affective shifting in humans: Evidence from a reversal learning paradigm. *Brain, 126*, 1830–1837.

Gray, J. A., & McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system* (2nd ed.). New York: Oxford University Press.

Gullo, M. J., & Dawe, S. (2008). Impulsivity and adolescent substance use: Rashly dismissed as "all-bad"? *Neuroscience and Biobehavioral Reviews, 32*, 1507–1518. doi:10.1016/j.neubiorev.2008.06.003.

Gullo, M. J., Jackson, C. J., & Dawe, S. (2010). Impulsivity and reversal learning in hazardous alcohol use. *Personality and Individual Differences, 48*(2), 123–127. doi:10.1016/j.paid.2009.09.006.

Harlow, J. M. (1868). Recovery from the passage of an iron bar through the head. Reprinted in *History of Psychiatry, 4*(1993), 274–281.

Hildebrandt, H., Brokate, B., Fink, F., Muller, S. V., & Eling, P. (2008). Impaired stimulus-outcome but preserved stimulus-response shifting in young substance-dependent individuals. *Journal of Clinical and Experimental Neuropsychology, 30*, 946–955. doi:10.1080/13803390801894699.

Inattention

► Attention Deficit Hyperactivity Disorder

Incentives and Student Learning

Wayne A. Grove[1], Lester Hadsell[2]
[1]Department of Economics, Le Moyne College, Syracuse, NY, USA
[2]Department of Economics, SUNY-College at Oneonta, Oneonta, NY, USA

Synonyms

Encouragement; Inspiration; Provocation; Reason to learn

Definition

Generally, incentives for learning can be defined as an inducement or supplemental reward that serves as a motivational device for intended learning. What kinds of incentives, especially financial, improve student learning? This question is salient worldwide, but particularly in the USA where, despite being the richest of the 41 OECD countries, US students' math, science, and reading abilities rank them in the middle and below that of the OECD countries (Fryer 2010, p. 3). The American student high school graduation rate of about 70% is low compared to OECD countries, with students in urban areas faring much worse (Education at a Glance 2007). Within the USA, a stark Hispanic/black-white learning gap persists, with rates of underperformance roughly twice as high for minorities as for whites. Colleges, universities, and employers report that too many high school graduates do not possess the basic skills and knowledge necessary for career success. All the foregoing is true despite a more than doubling of the spending per pupil in the USA since the 1970s.

These poor educational outcomes exist despite their importance for students' economic and social success. In consequence, policymakers and researchers have particularly focused on the role played by incentives for students, families, teachers, administrators, and for entire schools.

In this entry, we review a selection of the emerging scholarship of educational reform initiatives regarding incentives and learning. Most of the empirical work has focused on primary and secondary education, although there is some recent evidence from post-secondary schools. As economists, we take a particular interest in the role of monetary incentives and market-based initiatives and focus on those in this piece.

Theoretical Background

Learning and Incentives

A primary goal of elementary and secondary education is for children to develop basic academic and social skills and noncognitive attributes (e.g., perseverance, dependability, and consistency) necessary for productive citizenship and entry into the work force, a training program, or college. Despite the broader range of desired educational outcomes, policymakers focus on the learning of particular subject material. The lack of learning, to simplify, may result either from students themselves or from a problem with the complements to students' learning. On the first count, students may lack motivation to learn or may highly discount the future (so that the payoff to academic effort is overwhelmed by the immediacy of alternative uses of their time). Alternatively, factors beyond students' control may be contributing: ineffective teachers and administrators and unengaged parents and peers. The challenge, then, is to get students to exert effort, for the effort to yield achievement, and to aid the process with educational and social support.

The theory of student learning entails motivation (intrinsic and extrinsic) determining effort which yields learning depending upon innate ability (the ease of turning effort into learning) and support. The latter, support, refers to the quality of teaching, the relationship with the teacher, the classroom and school learning environment, parental and family support, and so on. Thus, aside from individual aptitude, learning is determined by effort which results from motivation.

How might financial incentives help overcome the roadblocks to learning and attainment mentioned in the introduction? First, a variety of incentives might get students to exert more effort. Large and growing wage premiums for high school, college, and professional education would seem already to provide an extrinsic incentive to study and learn. Research shows, though, that many children and young adults place a low value today on long-term rewards: that is, they highly discount future outcomes. So to motivate such students to study now requires either more immediate rewards or a better understanding of the link between studying now and the rest of their lives. Many students who are aware of the big financial benefits of completing college fail to exert academic effort, perhaps because they lack role models to envision that such opportunities are available to them. Incentives ranging from direct payment for performance on standardized tests to payments to families based on student effort (e.g., attendance) have been attempted, as discussed in more detail below.

Second, how might incentives overcome the lack of knowledge of how to convert effort into learning, namely, how to effectively study, complete assignments, and learn material that prevents student effort from yielding achievement? One solution may be rewarding the inputs in the learning process rather than the outputs. Recent programs show promise on this front (e.g., Fryer 2010).

Finally, how might incentives alter administrators', teachers', parents', and fellow students' behavior to influence student achievement? Several incentive programs provide direct payments to administrators and teachers for improved student performance or simply putting forth greater effort (additional time with students or obtaining additional certification). Charter schools also fall within this realm. Some programs provide payments to parents based on students' attendance or exam scores.

Although policymakers have focused on the potential role of external rewards and incentives, educational psychologists (and some economists) have noted their limitations. In an extensive review of the literature, Deci et al. (1999) conclude that the manner in which students respond to incentives rests on several key factors, including the student's own goals and level of intrinsic motivation (which determines the value of the task to them) and their perceived likelihood of success.

While much of the empirical work in Education Psychology concludes that extrinsic rewards are helpful in getting students to do unpleasant work, such rewards have been found to be ineffective and even harmful in certain circumstances – for example, when they are seen as controlling or when they are used as incentive to get students to do work they otherwise enjoy; furthermore, subsequent interest, risk preference, effort, and emotion can suffer if extrinsic rewards are overemphasized. Consequently some experimental studies (e.g., Fryer 2010) measure changes in intrinsic motivation, using, for example, the Intrinsic Motivation Inventory, developed by Ryan (1982).

Methodology: Randomized Evaluation

A center piece of the recent search for effective educational policy solutions has been the use of randomized evaluation, with random assignment to treatment and control groups. This is especially important due to concerns of program effects given complex and multiple channels of causality. Let us say you use a new pedagogical approach in class and at the end of the year your students' learning is 20% higher than the average in the three other classes of the same grade and material. Can we attribute the increase to the pedagogical approach? Or to you as a teacher versus the rest? Or might an unusual mix of students in your class account for the outcome? This selection bias problem, ensuring that participants and nonparticipants do not systematically differ, is the central difficulty that randomization seeks to avoid.

Important Scientific Research and Open Questions

Student Incentives

Recent studies by economists have examined the effectiveness of a wide range of monetary incentives in a variety of settings in several countries. Direct incentives for K-12 and college students take the form of cash payments for performance on standardized exams (e.g., Advanced Placement exams, Regents exams in New York State, exit exams in Israel), school attendance, and college enrollment. Such incentives generally appear to have positive effects.

Reward Inputs or Outcomes?

Fryer (2010) describes a series of school-based randomized trials in over 250 urban schools designed to test the impact of financial incentives on student achievement. His results suggest that student incentives increase achievement (and are less costly) when the rewards are given for inputs to the educational production function, while incentives tied to output are not effective. He suggests that incentives for inputs may be more effective because students do not know how to turn their motivation for rewards into achievement. Fryer also finds no evidence that monetary incentives decrease intrinsic motivation.

In contrast, here are two studies with some evidence that rewarding outcomes works. Merit scholarship for girls in Kenya generated significant gains in academic exam scores and yielded positive externalities (Kremer et al. 2004). In Coshocton, Ohio, 3rd- through 6th-grade students received cash payments for the successful completion of standardized tests (Bettinger 2010). Young children responded to the "paying to learn" program by improving math scores but not the test results for reading, social science, and science.

Motivation and Support

In a randomized field experiment at a large Canadian university (Angrist et al. 2009), first-year undergraduates were assigned to one of three treatment groups: (1) services such as peer advising and organized study groups, (2) substantial merit scholarship for good grades, and (3) both services and scholarships. Several interesting results emerge. First, use of services was much greater when combined with a financial incentive. Second, none of the interventions affected males, whereas females' grades improved for both treatments with scholarships. Finally, retention rates improved for females who received both services and scholarships.

The Dallas-based Advanced Placement (AP) Incentive Program involved payments both to 11th- and 12th-grade students and to their teachers for passing AP tests. The program improved students' long run academic performance, namely, attending college, collegiate GPAs, and persistence in college beyond the freshman year (Jackson 2010). While the program appears to have improved the outcomes of students who would have attended college anyway, most notably it increased the college graduation rate of black and Hispanic students, groups that tend to underperform in college. Thus, this program appears to have generated lasting positive and large effects.

Outcome Rewards Work for Higher Achieving Students

Angrist and Lavy (2009) report that cash incentives increased the certification rates of Israeli girls (but not of boys), apparently because the girls devoted extra time to exam preparation. The effect on girls was largely driven by an increase in passing rates among those who had a relatively high chance of passing these exams to begin with, rather than for low-achieving students.

In an example of who responds to incentives, economics and business freshman at the University of Amsterdam were offered either a high or a low financial reward for passing all first-year requirements compared to a control group with no reward (Leuven et al. 2010). Although the passing rate and accumulated credits did not differ between the three groups, higher compensation did elicit better outcomes for students with higher math skills and more highly educated fathers.

Family Incentives: Rewarding Student and Family Inputs

Indirect incentives focus on withholding benefits for families on public assistance whose children do not meet certain academic criteria (e.g., minimum attendance levels). Such "conditional cash penalties" are in effect in such diverse areas as Mexico (PROGRESA) and Wisconsin in the USA (Learnfare).

Mexico's antipoverty program, PROGRESA provides monetary transfers to families contingent on their children's regular attendance at school. A randomized social experiment, PROGRESA increased schooling attainment by reducing dropout rates and facilitating grade progression, particularly during the transition from primary to secondary school (Behrman et al. 2001). Since most commonly females tend to respond more to incentives than males, it is notable that the PROGRESA treatment effects for boys exceeded that of girls.

Dee (2009), studying Wisconsin's "Learnfare" program, finds that well-designed financial incentives, those that reward effort rather than direct performance, can be effective in improving the school persistence of at-risk students at scale. He concludes, "Learnfare closed the enrollment gap between baseline dropouts and school attendees by 41%."

In New York City beginning in 2007, a privately funded conditional cash transfer program offered an extensive set of rewards (averaging $6,000 per family in its first 2 years) in three areas (Riccio et al. 2010):

- Education-focused conditions, which include meeting goals for children's attendance in school, achievement levels on standardized tests, and other school progress markers, as well as parents' engagement with their children's education
- Health-focused conditions, which include maintaining health insurance coverage for parents and their children, as well as obtaining age-appropriate preventive medical and dental checkups for each family member
- Workforce-focused conditions, aimed at parents, which include sustaining full-time work and participation in approved education or job training activities

The program seems to have positively affected the last two areas above but not academic outcomes.

Teacher Incentives

Performance-based pay for teachers attempts to influence student performance via teacher effort (from attendance to additional time after school helping students). Both individual-based and group-based incentives for teachers have been studied. For the former, teacher effort (or more precisely, student outcomes) and reward are directly linked whereas in the latter effort and reward are measured at the school level (changes in school-level student performance is met with school-level rewards/punishments). Individual teacher-level incentives have been found to be more effective than group incentives – probably due to free-riding with the group incentives. Recent research on teacher incentives in the USA finds that teachers sometimes react strategically by, for example, reclassifying poor-performing students or even cheating (Jacob 2002; Jacob and Levitt 2003).

Figlio and Kenny (2006) find that that test scores are higher in schools that offer individual teacher incentives for good performance, including a particularly strong relationship for schools that may have the least parental oversight. Since this study was not a randomized evaluation, the authors cannot determine whether this relationship results from more effort by teachers or better schools adopting teaching incentives.

A flurry of new research has occurred recently investigating the benefits of explicit incentives for student learning in developing countries, for example, in India (Muralidharan and Sundararaman 2009; Duflo and Hanna 2005) and Kenya (Kremer et al. 2004). The findings are generally positive: improvement in test scores (of around 0.2 standard deviations), with spillover effects, and increased teacher attendance, but with some evidence that the incentives lead to more test prep rather than more effort.

School-Level Changes and Incentives

Market-based incentives meant to increase competition for students and associated funding have been introduced in the USA (and elsewhere) at the national and local levels. In the USA, the No Child Left Behind Act, signed into law in 2001, was a response at the national level to the poor learning and graduation rates of America's youth and the debate about education policy precipitated by the 1983 publication of the federal government's report on the state of America's schools, *A Nation at Risk* (National Commission on Excellence in Education). NCLB changed incentives regarding standardized tests, creating penalizes if students do not meet standards ("minimum requirements"?) or do not show year-to-year improvements. If all students fail to meet, or are not making progress toward, minimum standards, schools could be labeled "underperforming" which allows students to transfer to other schools and threatens reduced funding for the school and removal of administrators. The Obama administration modified NCLB to improve state-adopted learning standards, and to focus on the worse-performing 5% of schools (threatening to replace the principals) and well-performing schools (allow more latitude to innovate).

The following studies provide evidence of student learning benefits of particular changes but no evidence that competition between schools improved educational outcomes.

Some evidence exists that lower-performing students score better at the expense of their higher-performing classmates under programs like NCLB (Neal and Schanzenbach 2007). This likely results from the incentive structure: schools are sanctioned if too many students are not performing up to a minimum standard. Thus, focus – effort and resources – is placed on improving the performance of students near the minimum level.

At the state and local levels, voucher programs and charter schools are increasingly being used. Several countries, the USA included, have initiated programs designed to inject competition into the primary and secondary education market. Voucher programs provide public funds so that students may attend any school, although the choice is often limited to nonsectarian institutions. Charter schools are privately run (typically publicly funded) alternatives to public run schools. The idea is that competition will spur effort and innovation, leading to improved teaching techniques.

Although we will not survey the voluminous literature on charter schools, we will indicate the very significant learning gains from the Knowledge is Power Program (KIPP) charter schools (Angrist et al. 2010). The KIPP schools embrace a No Excuses approach of public education, have a longer school day and year, selective hiring of teachers, strict behavior norms, and a focus on traditional reading and math skills. In Boston, charter school students outperform "pilot schools," which are a public school alternative to charter schools in that they have some of the independence of charter schools but operate within the school districts, face little risk of closure, and are covered by many of the same collective bargaining provisions as traditional public schools (Abdulkadiroglu et al. 2009).

According to Rouse and Barrow (2009), a survey of the empirical evidence indicates limited benefits of voucher programs. According to the authors "The best research to date finds relatively small achievement gains for students offered education vouchers, most of which are not statistically different from zero. Further, what little evidence exists regarding the potential for public schools to respond to increased competitive pressure generated by vouchers suggests that one should remain wary that large improvements would result from a more comprehensive voucher system." They continue, "Many questions remain unanswered, however, including whether vouchers have longer-run impacts on outcomes such as graduation rates, college enrollment, or even future wages, and whether vouchers might nevertheless provide a cost neutral alternative to our current system of public education provision at the elementary and secondary school level." Some research does report positive outcomes, for example, in Columbia (Angrist et al. 2006), Charlotte, North Carolina (Hastings and Weinstein 2007), and Florida (marginally higher scores, Figlio and Rouse 2006).

Clark (2009) finds large student achievement gains in British schools in which the vote to opt out of local authority and to become autonomous barely won compared to schools in which it barely lost. The gains seem to result from changes in the teaching staff. This reform effort, though, appears not to have generated spillover effects for neighboring schools, as the school choice advocates argue.

General Conclusion and Open Questions

A preliminary finding (e.g., Fryer 2010) is that incentives for completion of tasks on the input side (e.g., attendance, reading) are more effective than similar incentives for attainment on the output side (exam scores, grades). In addition to students and families, does this apply to teachers and administrators?

The disparate findings indicate that the particulars of the incentive program and the school and students affected matter a great deal. The devil is in the details. Programs that emphasize individual rewards are more likely to encourage greater effort and better outcomes than programs whose structure allows for more free-riding (as when rewards for good performance are shared among participants).

We also do not know enough about the likely beneficiaries of incentives. Whereas NCLB targets low performing students and appears to have some success in doing so, most studies discussed in this chapter show that higher achieving students are more likely to increase performance in response to incentives to do so. Some studies indicate that the lowest performing students fail to increase their achievement while other studies show the opposite. Some studies indicate improvement for females but not males.

Most of the programs using financial incentives to improve student outcomes are fairly new, with many unanswered questions. Longer-run impacts are still being measured. Thus, it is not entirely clear what the effects are on graduation rates, college enrollment, and attitudes toward life-long learning.

Finally, cost effectiveness has not yet been a major point of study. Costs will surely become increasingly important in the current and future era of fiscal constraints.

Cross-References

► Autonomous Learning and Effective Engagement
► Engagement in Learning
► Student-Centered Learning
► Styles of Engagement in Learning

References

Abdulkadiroglu, A., Angrist, J., Dynarski, S., Kane, T. J., & Pathak, P. (2009). Accountability and flexibility in public schools: evidence from Boston's charters and pilots. NBER Working Paper No. 15549, Cambridge, MA: NBER.

Angrist, J., & Lavy, V. (2009). The effects of high stakes high school achievement awards: Evidence from a group randomized trial. *The American Economic Review, 99*, 1384–1414.

Angrist, J., Bettinger, E., & Kremer, M. (2006). Long-term educational consequences of secondary school vouchers: Evidence from administrative records in Colombia. *The American Economic Review, 96*, 847–862.

Angrist, J., Lang, D., & Oreopoulos, P. (2009). Incentives and services for college achievement: Evidence from a randomized trial. *American Economic Journal: Applied Economics, 1*, 136–163.

Angrist, J., Dynarski, S., Kane, T. J., Pathak, P., Walters, C.R. (2010). Who benefits from KIPP? NBER Working Paper No. 15740. Cambridge, MA: NBER.

Behrman, J., Sengupta, P., Todd, P. (2001). Progressing through PROGRESA: An impact assessment of a school subsidy experiment. Penn Institute for Economic Research Working Paper 01–033. http://pier.econ.upenn.edu/Archive/01-033.pdf. Accessed 3 June 2010.

Bettinger, E. (2010). Paying to learn: The effect of financial incentives on elementary school test scores. NBER Working Paper No. 16333. Cambridge, MA: NBER.

Clark, D. (2009). The performance and competitive effects of school autonomy. *Journal of Political Economy, 117*, 745–783.

Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin, 125*, 627–668.

Dee, T. (2009). Conditional cash penalties in education: Evidence from the learnfare experiment. NBER Working Paper No. 15126. Cambridge, MA: NBER.

Duflo, E., & Hanna, R. (2005). Monitoring works: Getting teachers to come to school. NBER Working Paper No. 11880. Cambridge, MA: NBER.

OECD. (2007). *Education at a Glance*. Paris: Organisation for Economic Co-Operation and Development.

Figlio, D. N., & Kenny, L. (2006). Individual teacher incentives and student performance. NBER Working Paper No. 12627. Cambridge, MA: NBER.

Figlio, D. N., & Rouse, C. E. (2006). Do accountability and voucher threats improve low-performing schools? *Journal of Public Economics, 90*, 239–255.

Fryer, R. (2010). Financial incentives and student achievement: Evidence from randomized trials. NBER Working Paper No. 15898. Cambridge, MA: NBER.

Hastings, J. S., & Weinstein, J. M. (2007). No child left behind: Estimating the impact on choices and student outcomes. NBER Working Paper No. 13009. Cambridge, MA: NBER.

Jackson, C. K. (2010). A stitch in time: The effects of a novel incentive-based high-school intervention -on college outcomes. NBER Working Paper No. 15722. Cambridge, MA: NBER.

Jacob, B. A. (2002). Accountability, incentives and behavior: The impact of high-stakes testing in the Chicago Public Schools. NBER Working Paper No. 89868. Cambridge, MA: NBER.

Jacob, B., & Levitt, S. (2003). Rotten apples: An investigation of the prevalence and predictors of teacher cheating. NBER Working Paper No. 9413. Cambridge, MA: NBER.

Kremer, M., Miguel, E., & Thornton, R. (2004). Incentives to learn. NBER Working Paper No. 10971. Cambridge, MA: NBER.

Leuven, E., Oosterbeek, H., & van der Klaauw, B. (2010). The effect of financial rewards on students' achievements: Evidence from a randomized experiment. *Journal of the European Economic Association, 8*, 1243–1265.

Muralidharan, K., & Sundararaman, V. (2009). Teacher performance pay: Experimental evidence from India. NBER Working Paper No. 15323. Cambridge, MA: NBER.

National Center for Education Statistics. (2010). *The nation's report card: Trial urban district assessment reading 2009 (NCES 2010–459)*. Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

Neal, D., & Schanzenbach, D. W. (2007). Left behind by design: Proficiency counts and test-based accountability. NBER Working Paper No. 13293. Cambridge, MA: NBER.

Riccio, J., Dechausay, N., Greenberg, D., Miller, C., Rucks, Z., & Verma, N. (2010). Toward reduced poverty across generations early findings from New York City's Conditional Cash Transfer Program. MDRC. www/mdrc.org. Accessed 19 April 2011.

Rouse, C. E., & Barrow, L. (2009). School vouchers and student achievement: Recent evidence and remaining questions. *Annual Review of Economics, 1*, 17–42.

Ryan, R. M. (1982). Control and information in the intrapersonal sphere: An extension of cognitive evaluation theory. *Journal of Personality and Social Psychology, 43*, 450–461.

Incidental Learning

Steve W. Kelly
Department of Psychology, University of Strathclyde, Glasgow, Scotland, UK

Synonyms

Experiential learning; Informal learning; Learning en-passant; Low involvement learning; Tacit knowing; Unconscious learning

Definition

Incidental learning refers to any learning that is unplanned or unintended. It develops while engaging in a task or activity and may also arise as a by-product of planned learning. "Incidental learning" can imply that the acquisition of knowledge is unconscious in nature, though in contrast to implicit learning, there is no expectation that such knowledge should remain largely inaccessible to conscious awareness. However, note that some articles may refer to implicit learning tasks as incidental without making the above distinction. There is also a suggestion, mainly from an educational perspective, that incidental learning involves subsequent conscious reflection on material that was consciously noted at time of study but not recognized as relevant or useful.

Theoretical Background

Incidental learning features mainly in the education/occupational literature and in the cognitive psychology literature. In the former, incidental learning is seen as a subset of "informal learning" which is unstructured and learner-led, the difference being that incidental learning is seen as almost always occurring in every situation. As this definition can be seen to incorporate a vast array of circumstances and knowledge bases, these models of incidental/informal learning cite factors such as life context of the learner, learning strategies, framing problems, and the need for some internal or external trigger to signal dissatisfaction with current solutions (e.g., Marswick and Watkins 2001).

In cognitive psychology, the definition of incidental learning is more likely to involve unconscious acquisition of information and the contrast between incidental and intentional learning of stimuli with a predefined stimulus set. Early research found dissociations between intentional and incidental learning with variables such as intra-list interference, distraction, incentive, and emotion being manipulated experimentally (e.g., Winnick and Lerner 1963). An example of a standard paradigm would be to require learning of geometric shapes of different colors; the shape would be intentionally learned as this was part of the study instructions but if color was also found to have been correctly remembered then this was taken as evidence for the incidental learning of color. While laboratory-based studies were demonstrating learning effects under incidental instructions, there was little evidence to suggest that such learning was commonplace in real life. Morton (1967) examined knowledge of the correspondence between the letters and numbers on telephone dials. Even experienced telephonists performed poorly on recognition and recall of this material.

Other studies which examined knowledge of similar correspondences and invariant information in the everyday environment (e.g., saturation advertising of changing local radio station wavelengths, shape of the new and old moon, features on coins) similarly found a lack of incidental learning of this material. While one conclusion from the early research would be that, similar to implicit learning, incidental learning is subserved by separate neural mechanisms or separate cognitive processes from intentional learning, failure to find learning of these specific stimulus dimensions in real life suggests that intentional learning may be nothing more than an artifact of the laboratory situation.

Important Scientific Research and Open Questions

Current evidence is more favorable toward both laboratory and real-world incidental learning. McGeorge and Burton (1990) demonstrated learning of a "rule" in an incidental learning task which involved an addition task on a series of four digit numbers. The rule is simply that the digit "3" appeared in each one of the four digit numbers. The so-called "digit invariance" effect found that when a surprise pseudo-recognition task was given, despite all test items being novel, numbers that contained a "3" were nevertheless "recognized" as being from the earlier study phase and numbers which did not contain a "3" were less likely to be rated as "old." This series of experiments gives strong support for the idea that this type of learning is not simply unreported intentional learning as the simple rule could not be elicited post-task.

There is some evidence to suggest that incidental learning may be underpinned by prototype formation (Kelly and Wilkin 2006) whereby all the individual instances of having seen a particular stimulus form, over time, into a prototypical representation. It is this representation that causes feelings of familiarity and recognition and these feelings are consciously accessible.

This would explain why previous real world incidental learning experiments failed to produce evidence for such learning: in recalling an item there is no place for a feeling of familiarity to have an effect. Real-world incidental learning has been shown (Kelly et al. 2001) when both correct and incorrect versions of the real-world stimuli have been presented suggesting certain characteristics that we encounter in everyday life can be encoded into memory without any effort to do so but as a consequence it takes a sensitive recognition task to elicit such knowledge.

Questions remain regarding the type of information that can be learned incidentally, what parameters are necessary for encoding (e.g., invariance, quantity, amount of detail, and attention/functionality), and what factors may mediate such information being accessible or inaccessible to conscious awareness across a variety of stimuli and learning parameters. The relation between this very specific and constrained definition of incidental learning in cognitive psychology and that used in education and occupational settings is also a matter for future debate as the latter would intuitively seem to encompass many more types of learning process and situation than the former.

Cross-References

▶ Implicit Sequence Learning
▶ Latent Learning
▶ Learning as a Side Effect
▶ Learning by Doing
▶ Mediators of Learning
▶ Recognition Learning
▶ Tacit Knowledge
▶ Task-Irrelevant Perceptual Learning
▶ Unconscious and Conscious Learning

References

Kelly, S. W., & Wilkin, K. (2006). A dual process account of digit invariance learning. *The Quarterly Journal of Experimental Psychology, 59*, 1664–1680.

Kelly, S. W., Burton, A. M., Kato, T., & Akamatsu, S. (2001). Incidental learning of real world regularities in Britain and Japan. *Psychological Science, 12*, 86–89.

Marswick, V. J., & Watkins, K. E. (2001). Informal and incidental learning. *New Directions for Adult and Continuing Education, 89*, 25–34.

McGeorge, P., & Burton, A. M. (1990). Semantic processing in an incidental learning task. *Quarterly Journal of Experimental Psychology, 42*, 597–609.

Morton, J. (1967). A singular lack of incidental learning. *Nature, 215*, 203–204.

Winnick, W. A., & Lerner, R. A. (1963). Intentional and incidental learning under distraction. *The American Journal of Psychology, 76*, 683–686.

Incidental Sequence Learning

► Implicit Sequence Learning

Incidental Vocabulary Learning

In vocabulary acquisition, a distinction is frequently made between incidental and intentional vocabulary acquisition. Incidental vocabulary acquisition is generally defined as the learning of vocabulary as the by-product of any activity not explicitly geared to vocabulary learning. The most frequently quoted example being vocabulary learning as a by-product of reading.

Inclination

► Attitudes – Formation and Change

Inclusion

► Inclusive Teaching and Learning

Inclusive Education

► Inclusive Teaching and Learning

Inclusive Fitness

Refers to the fitness of an individual organism as measured in terms of its own reproductive success and that of its kin (with each relative being valued according to the probability of shared genetic information).

Inclusive Practice

► Inclusive Teaching and Learning

Inclusive Teaching and Learning

Pamela L. Arnold
Old Dominion University, Darden College of Education, The Center for Educational Partnerships, Norfolk, VA, USA

I

Synonyms

Inclusive education; Inclusive practice; Inclusion

Definition

Inclusive teaching and learning are instructional components of inclusion, a broad term that refers to education of students along a range of diversities in a common educational community. These diversities may include dimensions of gender, language, ethnicity, socioeconomic status, and ability. Areas of focus for inclusion may vary according to demographic and social characteristics of a particular setting. Ainscow (1998) describes inclusion as a process of school improvement whereby stakeholders engage in an ongoing exploration of school systems in the pursuit of excellence for *all* students. Inclusive education is founded on the premise that all students are entitled to take part in all subjects and activities. To this end, inclusive educational settings seek to ensure that (1) instructional planning considers the needs of all students; (2) curricula promote understanding of and respect for diversity; (3) all students participate during instruction; (4) varied teaching approaches are used; (5) students experience success at their individual level; (6) all students take part in assessment systems; and (7) learning difficulties are seen as professional development opportunities (Ainscow 1998).

Inclusion has been conceptualized as bringing necessary supports for learning to children with disabilities in the general education classroom, rather than pulling students out to bring them to services

(Ruijs and Peetsma 2009). Many scholars have expanded beyond a location of service delivery definition to discuss qualitative aspects of inclusive education. Giangreco et al. (1994) outline six basic characteristics: (1) *all* students are welcomed in general education settings; (2) students with and without disabilities are educated together in groups that mirror natural proportions of people with disabilities in the general population; (3) all students participate in shared learning experiences with accommodations and supports as needed; (4) settings are those in which students without disabilities typically learn; (5) instruction is designed to consider academic and social learning for all students; (6) each of the aforementioned is ongoing. Additionally, inclusive education requires collaboration among parents, paraprofessionals, and support services providers (Ainscow 1998; Farrell 2000; Villa et al. 2005). Another commonly articulated characteristic of inclusive education is that difference is regarded as a valuable aspect of human experience, exposure to which is beneficial for all students (Ainscow 1998).

The term inclusion or inclusive has emerged in the literature as distinct from the terms "mainstreaming" or "integration" (Farrell 2000). All three terms refer to education of students with disabilities in general settings (Giangreco and Baumgart 1995). However, as Farrell (2000) notes, the terms mainstreaming and integration have been used to characterize a range of experiences for students with disabilities, including highly limited participation such as occasional visits to a general education learning community. As a result, the terms inclusion and inclusive began to be employed by scholars and practitioners desiring to communicate qualitative aspects of the type of experience they envisioned in a system where all students are educated together. Giangreco and Baumgart (1995) explain, whereas mainstreaming focuses primarily on the physical placement of students with disabilities, inclusive education suggests a reconstruction of classes and schools to welcome and provide meaningful education to all children, together. Ainscow (1998) also defines inclusion as distinct from the terms "mainstreaming" and "integration," suggesting that it characterizes a process whereby a school system continuously explores how effectively it responds to the diverse learning needs of all attending students, and restructures accordingly.

Theoretical Background

Some have described inclusive education as a set of social values (e.g., equity, access, individualization, community) and a philosophical vantage point from which educational decisions are made (Giangreco et al. 1994). From this point of view, difference is seen as a learning benefit to *all* students rather than as an obstacle. Focus is on designing programs, classes, and schools where it is possible for all students in the setting to learn, rather than assuming the individual should fit the setting first.

Much of the philosophical foundation for inclusive education has been drawn from equity concerns and the rejection of "separate but equal" school experiences. Schools in the United States are now required by law to provide a free and appropriate public education in the least restrictive environment (LRE) to all students regardless of disability (Villa et al. 2005). The provision for the LRE requires schools to educate students with disabilities alongside their peers who do not have disabilities. Students may be placed in more restrictive settings along a continuum of placements only if there is documented evidence that their individual educational needs cannot be met in a general educational setting (Salend 2011).

Critical scholars have explored the issue of inclusion, arguing that select ideas and discourses about "normalcy" from the natural and social sciences position students with disabilities as disadvantaged or deviant. This results in the perpetuation of inequitable educational opportunities for these students (McPhail and Freeman 2005). Others have raised questions about the efficacy, cost, and fairness of maintaining dual systems of special and general education. Ainscow (1998) suggests that linking the two fields of special and general education through inclusive educational models offers the opportunity to develop forms of schooling that will be more effective for all students (p.75).

In the current context of high stakes testing for all students, provisions requiring that all students be taught by teachers who are highly qualified in their content area, coupled with the emphasis on the LRE, suggest that students with disabilities will increasingly be included in general education classrooms (Villa et al. 2005). For these reasons, there is a clear need for research into the effects of inclusion programs on the learning of students with and without identified disabilities, and synthetic reviews of the extant empirical evidence.

Important Scientific Research and Open Questions

Many small, descriptive studies have explored effects of inclusive programming on students with and without disabilities, as well as impacts on teachers. There are few large-scale studies documenting the design or effects of the large number of varied programs calling themselves inclusive. Research on inclusive programs is limited by problems that characterize much research in education, such as ensuring a level of equivalence among groups compared and defining the conditions of study – in this case, what makes an inclusive program inclusive (Salend and Duhaney 1999). It is difficult to use matched control group designs due to ethical problems of allocating resources to students solely for the purpose of conducting research (Farrell 2000). Furthermore, the term "students with disabilities" includes subgroups of students with vastly different characteristics, making it difficult to compare and generalize (Farrell 2000; Ruijs and Peetsma 2009). Despite these challenges, there are substantial bodies of research on inclusive education centering around five major themes: (1) academic effects for students with disabilities, (2) academic effects for students without disabilities, (3) social effects for students with disabilities, (4) social effects for students without disabilities, and (5) impacts on teachers (Farrell 2000; Ruijs and Peetsma 2009; Salend and Duhaney 1999).

Ruijs and Peetsma (2009) reviewed literature on the cognitive and achievement effects of inclusion and found overall positive to neutral effects of such programming on students with disabilities. Previous reviews (Farrell 2000; Salend and Duhaney 1999) identified mixed findings. Salend and Duhaney (1999) found many studies reporting academic gains for students with disabilities in various areas. Studies documenting "negative" effects typically noted lack of appropriate specialized adaptations or accommodations in the inclusive setting (Salend and Duhaney 1999). Giangreco and Baumgart (1995) make the case that structuring necessary accommodations and adaptations is so integral to ensuring students with disabilities are able to participate meaningfully in the learning environment, programs lacking these features should not be labeled "inclusive." Reviewers consistently found that inclusive placements did not interfere with the academic performance of students without disabilities (Ruijs and Peetsma 2009; Salend and Duhaney 1999).

Farrell (2000) concludes that students with disabilities appear to benefit socially from inclusion, while Salend and Duhaney (1999) found more complexity around social effects. For students with more severe disabilities, studies reviewed indicated more frequent interaction, increased social support and longer-lasting friendships. However, interactions tended toward assistance and declined over time. Some studies found students with mild disabilities in inclusive settings were rated similarly to students without disabilities on social measures, while others indicated these students were more rejected by classmates and had lower self-perceptions. Studies did not consider whether these same students would have been equally or more rejected by typical peers if they were in a non-inclusive setting. Ruijs and Peetsma (2009) note the lack of control groups in most studies, and assert that while students with disabilities in inclusive settings were generally less well liked than peers without disabilities, it is not possible to draw conclusions about whether these effects are a result of inclusion or if the same or more significant effects would be obtained for similar students in more restrictive settings. With respect to the social effects of inclusion for students without disabilities, reviews found these students held more positive attitudes overall toward people with disabilities (Farrell 2000; Ruijs and Peetsma 2009; Salend and Duhaney 1999).

Concerning the impact of inclusion on teachers, Farrell (2000) found general educators exhibited positive attitudes about inclusion, though were less positive when assigned to teach a student with a disability. Salend and Duhaney (1999) found differing attitudes shaped by numerous variables, including implementation success; student characteristics; availability of supports; and time for collaboration. Other effects for general educators found by Salend and Duhaney (1999) included perceived increased skill in meeting the individual needs of all students, and increased confidence in teaching ability. Farrell (2000) reviewed data that indicated when the inclusion process is well managed, general educators adopt more positive stances toward professional collaboration. General educator concerns about inclusion included the impact on students without disabilities; lack of funds for supports; and limited time for collaboration (Salend and Duhaney 1999). Special educators identified enhanced knowledge of the general education curriculum and greater work satisfaction derived from being part of a common learning environment as benefits of inclusion, while subordinate positioning in shared classroom settings and potential loss of necessary supports for individuals with disabilities were identified as concerns (Salend and Duhaney 1999).

A range of specific instructional and organizational approaches have been identified as potential cornerstones of effective inclusive practice, including differentiated instruction and universal design; interdisciplinary curriculum; use of technology; student collaboration and peer-mediated instruction; curricular supports and accommodations; social skills instruction; authentic assessments of student performance; administrative leadership support; ongoing professional development; collaborative instruction and co-teaching; and heterogeneous groupings (Villa et al. 2005). However, researchers have noted that there are major differences in practices in settings labeled inclusive, in terms of structures and supports; instructional methods utilized; and the extent to which students with disabilities are included for all, most, or only part of the school day (Farrell 2000; Ruijs and Peetsma 2009). Farrell (2000) notes that the success of any given inclusion program could be directly related to the quality of in class support, both in terms of availability and expertise. Few studies explicitly identify the discrete features of differing inclusive educational programs and compare them with respect to their impact on students with and without disabilities. These are areas in need of further investigation. Research on teacher attitudes toward inclusion is also relevant because these attitudes may impact how inclusive education is delivered to and experienced by students. This issue becomes even more important in an era of high stakes testing in which there is a concomitant move to include more students with disabilities in testing pools and at the same time link teacher performance evaluation to student outcomes. More research on teacher attitudes toward inclusive education and how these attitudes affect educational practices would be particularly timely given the current educational social and political milieu.

Cross-References

► Change of Values Through Learning in Organizations
► Choreographies of School Learning
► School Climate and Learning
► Well-Being and Learning in School

References

Ainscow, M. (1998). Exploring links between special needs and school improvement. *Support for Learning, 13*(2), 70–75.

Farrell, P. (2000). The impact of research on developments in inclusive education. *International Journal of Inclusive Education, 4*(2), 153–162.

Giangreco, M. F., & Baumgart, D. M. J. (1995). How inclusion can facilitate teaching and learning. *Intervention in School and Clinic, 30*(5), 273–278.

Giangreco, M., Cloninger, C., Dennis, R., & Edelman, S. (1994). Problem-solving methods to facilitate inclusive education. In J. Thousand, R. Villa, & A. Nevin (Eds.), *Creativity and collaborative learning: A practical guide to empowering students and teachers* (pp. 321–346). Baltimore: Brookes.

McPhail, J. C., & Freeman, J. G. (2005). Beyond prejudice: Thinking toward genuine inclusion. *Learning Disabilities Research & Practice, 20*(4), 254–267.

Ruijs, N. M., & Peetsma, T. T. D. (2009). Effects of inclusion on students with and without special educational needs reviewed. *Educational Research Review, 4*(2), 67–79.

Salend, S. J. (2011). *Creating inclusive classrooms: Effective and reflective practices.* Boston: Pearson.

Salend, S. J., & Garrick Duhaney, L. M. (1999). The impact of inclusion on students with and without disabilities and their educators. *Remedial & Special Education, 20*(2), 114.

Villa, R. A., Thousand, J. S., Nevin, A., & Liston, A. (2005). Successful inclusive practices in middle and secondary schools. *American Secondary Education, 33*(3), 33–50.

Incoherences as Driving Forces for Concept Development

► Discontinuities for Mental Models

Incompatibility Effects

► Emotions in Cognitive Conflicts

Incongruity

Incongruity means a lack of congruence as the quality of agreeing; being suitable and appropriate. Other words for incongruity are inappropriateness, discrepancy, inconsistency, incompatibility.

Inconsistency

► Compartmentalization in Learning

Incremental Learning

The term "incremental learning" is often used for sequential or constructive learning in contrast to batch or epoch learning (Bertsekas and Tsitsiklis 1996). Incremental learning is based on the principle of starting with simple and basic principles before advancing to more complex information. Incremental learning happens in bits and pieces, and successful retention of knowledge is based upon previously attained knowledge. As a style of acquiring knowledge and skills, the concept of incremental learning can be found in psychology as well as in machine learning and refers to situations where input data come only in sequence, and a timely updating model is crucial for actions.

In psychology, the term "incremental learning" can be traced back to Thorndike but can also be found in more recent theories of how people learn (e.g., Bransford et al. 2000). However, the term "incremental learning" plays an important role also in the field of machine learning which includes algorithms for incremental learning of concept descriptions (e.g., Reinke and Michalski 1988) and perception of visual categories (see the entry on ► Incremental Learning of Visual Categories).

Cross-References

► Cumulative Learning

References

Bertsekas, D. P., & Tsitsiklis, J. N., (1996). Neuro-Dynamic Programming. Belmont: Athena Scientific.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). How people learn: Brain, mind, experience, and school (Expanded ed.). Washington, DC: National Academy Press.

Reinke, R. E., & Michalski, R. S. (1988). Incremental learning of concept descriptions: A method and experimental results. In J. E. Hayes, D. Michie, & J. Richards (Eds.), *Machine intelligence 11: Logic and the acquisition of knowledge* (pp. 263–288). Oxford: Clarendon Press.

Incremental Learning of Visual Categories

Stephan Kirstein, Heiko Wersing
Honda Research Institute Europe GmbH, Offenbach, Germany

Definition

Incremental learning of visual categories denotes the capability of a visual perceptual system to build up an increasing repertoire of visual concepts based on a sequence of experiences. A visual category is here defined as a possibly large group of individual objects that share similar properties like shape, appearance, or color. Biological visual systems achieve this function very efficiently for their behaviorally relevant categories, where an appropriate generation and selection of features is considered to be responsible for good generalization. Static visual learning models with a fixed a priori set of trainable parameters face severe problems for dynamically changing training sets. In contrast to non-incremental visual approaches, incremental ones approach this problem by growing categorical representations that adapt to successively available training stimuli.

Theoretical Background

Visual categories can be differentiated according to their abstraction level into superordinate, basic level, and subordinate categories (Rosch et al. 1976). Superordinate categories share several visual properties ("sheepdogs"), whereas basic level categories ("dogs") may have a larger visual variability. Subordinate categories ("animals") are rather defined by behavioral concepts instead of visual attributes.

Similarity or dissimilarity of categories is generally formalized through the concept of visual features: Local features can be generic object parts or substructures of parts like specific edge combinations. Global features characterize holistic properties like orientation histograms or distribution moments of the object silhouette. Learning appropriate features is often the key problem in visual categorization algorithms. Most established visual feature learning methods are constrained to a stationary ensemble of training patterns, delivering a fixed feature set. On the contrary, the flexibility of incremental human visual category learning has been explained by the capability of perceptual learning (Goldstone 1998): Visual features are added, pruned, combined, or differentiated based on the requirements of the visual categorization task.

Incremental learning for human visual category perception is assumed to be the result of interacting anatomically segregated brain areas: The prefrontal cortex contributes strongly to working memory for attending a learning task, while the transfer from short-term memory (STM) to long-term memory (LTM) is associated with the mediotemporal lobe (MTL) (O'Reilly and Norman 2002). The MTL is responsible for the memory consolidation process of the visual knowledge into neocortical areas like inferotemporal cortex, being selective to shape categories.

Algorithmic solutions for visual category learning can be distinguished according to the way training data is made available to the algorithm: stationary ensemble, increasing training set with exhaustive memory, and a continuously changing limited training set. Especially the last case requires memory architectures incorporating both STM and LTM components.

The first case of a stationary ensemble is effectively dealt with by modern machine learning theory (Vapnik 2000). Although the theory is well developed, it cannot be directly generalized to incremental learning with nonstationary training sets.

For the second case of increasing training sets with exhaustive memory, training patterns are added and all previously seen data remains available to the learning approach. The main problem is to achieve the capability of revising feature representations that were learned initially but have to be adapted in later stages of learning. A typical example is the correlated appearance of a category-specific feature with an unrelated feature in the initial training. Later stages of learning should allow the pruning of the corresponding feature representation.

The third case of a continuously changing training set best matches the situation for human visual category learning, allowing only a limited short-term memory capacity. This task has also been phrased as the life-long learning problem, where an exhaustive memory of all training examples is prohibitive. For the incremental learning of categories, this changing training set requires to approach the well-known "*Stability-Plasticity Dilemma*" (Carpenter and Grossberg 1987): The fundamental conflict between the addition or correction of categorical knowledge (plasticity) and the long-term conservation of previously acquired information (stability).

Important Scientific Research and Open Questions

Categorization approaches can be partitioned into generative, discriminative, and hybrid models (Fritz 2008). Generative probabilistic methods first model the underlying joint probability for each category individually. Based on this model and the Bayes theorem, the posterior class probability is determined. The advantages of generative models are that prior knowledge can easily be incorporated and that typically few training examples are sufficient to reach good performance. In contrast to this, discriminant models like support vector machines (Vapnik 2000) directly learn the mapping from the training vectors to the desired category output. Such discriminant models tend to achieve a better categorization performance compared to generative models if a large training ensemble is available (Ng and Jordan 2001). But purely discriminative determination of category features induces a strong specialization toward already seen examples that causes a strong "catastrophic" forgetting effect for data that was removed from the visible training window. Life-long learning of categories therefore also requires a hybrid combination of discriminative and generative components that allows to keep nonredundant information of previously seen training examples efficiently in memory.

Category-specific features should neglect individual object-specific details and concentrate on reoccurring and stable features. The closer this feature representation is to the shared visual attributes of the categories (e.g., cars have wheels), the easier the category learning becomes. Parts-based methods (Leibe et al. 2004; Hasler et al. 2007) dominate most of the current work in this field. To obtain and describe relevant parts, local feature descriptors are computed and clustered across the category training examples. Good features deliver an optimal compromise between selectivity to the category and stability across different views and category exemplars. Another prominent feature learning approach for visual categorization is agglomerative clustering (Mikolajczyk et al. 2006).

The basic idea is to start with a large set of local features (e.g., line segments). During each iteration of the clustering process, the most similar features are merged together. The iterative clustering converges into a tree-like structure, where at the lowest level the original local features are represented and, in the root node, all local features are clustered together. For the learning of visual categories, typically, the intermediate clusters of the generated tree are used because they offer a good compromise between complexity and category specificity.

Compared to static learning models with a fixed finite set of adaptable parameters, incremental learning models can increase their representation complexity in a self-optimizing way. On the downside, this greater flexibility has made rigorous mathematical treatment very difficult and has kept incremental learning within a small niche of machine learning theory. Most incremental approaches therefore use heuristics to achieve a good trade-off between representation effort, memory capacity, and discrimination capability. To achieve self-optimization, a learning method has to decide when and where the categorical representation has to be enhanced based on direct or indirect error measures. Direct error measures are derived from categorization errors so that the representation is adapted based on erroneous training vectors (Kirstein et al. 2009). In contrast to this indirect measures are more connected to the representational accuracy like the locally accumulated quantization error. The representation is then extended in the vicinity of such local error hot spots. The definition of incremental insertion rules is crucial with respect to the categorization performance and determines convergence speed and allocated resources.

Due to the rapid advancement in mobile and cognitive robotics interactive learning techniques are becoming increasingly popular. The challenges typically lie in the speed of the learning method, to allow human interaction and a quick incorporation of newly acquired data. To achieve high learning speed, typically, dimensionality reduction or feature selection techniques are used so that learning only takes place in low-dimensional subspaces. Additionally, incremental learning techniques are popular in this context because of their greater flexibility with respect to a priori unknown categories. Interactivity during the learning process is also efficient for bootstrapping of the representation because the tutor directly obtains feedback what the learning system already knows and therefore can concentrate on the remaining errors. Thus, typically much less training data is required compared to traditional offline learning.

One of the general open questions of visual category learning is the scalability of the approaches to an arbitrary number of categories. So far, most approaches concentrate on single (e.g., pedestrians) or very few categories. This is caused by the large amount of a priori knowledge that is required for good categorization performance, but also by the strong focus on the development of isolated methods for feature extraction or learning. A stronger emphasis on larger integrated systems, addressing the co-development of feature and categorical representation for lifelong learning may allow a better scaling to much larger categorization systems. Also the scaling of current categorization approaches to basic or subordinate categories is still an open question because such categories commonly share distinctly less visual properties compared to the more common superordinate categories. For the categorization of every-day objects, however, most objects may belong to several categories at the same time. Nevertheless, categories are trained independently in most approaches. This is sufficient if the training time is irrelevant, but for interactive learning, the consideration of co-occurring categories is necessary. For the handling of co-occurring categories, the learning approach should be able to extract the defining features for each category based on a feature set reflecting all possible categories. Especially if the training data is incrementally acquired, errors in the feature selection process cannot be prevented so that additional correction mechanisms are required.

Cross-References

- ► Autonomous Learning
- ► Learning Algorithms
- ► Learning in Artificial Neural Networks
- ► Self-organized Learning
- ► Visual Perception Learning

References

Carpenter, G. A., & Grossberg, S. (1987). ART 2: Stable self-organization of pattern recognition codes for analog input patterns. *Applied Optics*, *26*(23), 4919–4930.

Fritz, M. (2008). *Modeling, representation and learning of Visual Categories*. Ph.D. thesis, Technical University of Darmstadt.

I

Goldstone, R. L. (1998). Perceptual learning. *Annual Review of Psychology, 49*, 585–612.
Hasler, S., Wersing, H., & Körner, E. (2007). A comparison of features in parts-based object recognition hierarchies. In *Proceedings of International Conference on Artificial Neural Networks* (pp. 210–219).
Kirstein, S., Denecke, A., Hasler, S., Wersing, H., Gross, H.-M., & Körner, E. (2009). A vision architecture for unconstrained and incremental learning of multiple categories. *Memetic Computing, 1*(4), 291–304.
Leibe, B., Leonardis, A., & Schiele, B. (2004). Combined object categorization and segmentation with an implicit shape model. *ECCV workshop on statistical learning in computer vision* (pp. 17–32). Prague.
Mikolajczyk, K., Leibe, B., & Schiele, B. (2006). Multiple object class detection with a generative model. In *Proceedings of the IEEE conference on computer vision and pattern recognition* (pp. 26–36). San Francisco.
Ng, A. Y., & Jordan, M. I. (2001). On discriminative vs. generative classifiers: A comparison of logistic regression and naive Bayes. In *Proceedings of the advances in neural information processing systems* (pp. 849–856).
O'Reilly, R. C., & Norman, K. A. (2002). Hippocampal and neocortical contributions to memory: Advances in the complementary learning systems framework. *Trends in Cognitive Sciences, 6*(12), 505–510.
Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8*, 382–439.
Vapnik, V. (2000). *The nature of statistical learning theory.* New York: Springer.

Incremental Theory

View that intelligence or ability is malleable and changeable.

Inculcation

► Enculturation and Acculturation

Independent Home Education

► Homeschooling and Teaching

Independent Learning

Kay Livingston
School of Education, University of Glasgow, College of Social Sciences, Glasgow, Scotland, UK

Synonyms

Autonomous learning; Self-directed learning; Self-regulated learning

Definition

Independent learning is a method or learning process where learners have ownership and control of their learning – they learn by their own actions and direct, regulate, and assess their own learning. The independent learner is able to set goals, make choices, and decisions about how to meet his learning needs, take responsibility for constructing and carrying out his own learning, monitor his progress toward achieving his learning goals, and self-assess the learning outcomes.

Theoretical Background

The concept of *independent learning* is associated with, or a part of other educational concepts and wider policy agendas, such as improving the educational experiences and outcomes for learners through student-centered learning approaches that personalize learning and enable the learner to take ownership of the learning process (Meyer et al. 2008). An understanding of how learners learn, both in terms of theories of cognition and their practical application, is central to developing the skills and strategies aimed at improving an individual's ability to learn independently (Meyer et al. 2008).

The theoretical background of independent learning draws from various philosophical, psychological, and sociological perspectives. Each of these traditions has influenced the development of ideas about independent learning – from the internal neural processes that are involved during learning to the many external influences that affect what people see and learn. The relationship between internal and external enables the learner to respond to the environment and has the ability to make creative and unique responses in each new situation that arises. The internal factors are the skills that individual learners have to acquire in order to become an independent learner. These skills include ► cognitive skills (memory, attention, and problem-solving), ► metacognitive skills (awareness of one's own cognitive functioning, understanding how to learn, and how to apply learning in different situations), and affective skills (feelings and emotions including self-reliance, self-efficacy, and motivation). The external factors in the learning process concern how the learner interacts and understands how to act in different environments (physical environment and material resources). External factors can include social interaction with others who enable or contribute to learners learning independently (e.g., parents, teachers, or peers).

Theories about learners taking control of their learning can be found in John Dewey's (1859–1952) work on the development of reflective thought. In his view, the most important goal of education is enabling individuals to take control of and responsibility for their own thinking in order to participate in a democratic society. In more recent times, growing interest in independent learning appears to have coincided with new ideas about learning in a rapidly changing technological and information society. Greater emphasis is placed on the need to develop lifelong learners who are able to continue learning and adapting to new knowledge and changing circumstances throughout their life. A transmission model of education, where information is transmitted to passive learners, is deemed an ineffective way to impart lasting knowledge and equip learners with the skills they need to learn how to learn and become capable of learning independently. It is suggested that the development of lasting competence and learning skills requires a shift from teacher-centered to student-centered approaches where the learner is actively practicing their learning skills and applying knowledge themselves. Independent learners must be able to organize their learning in a way that makes sense to them (Bruner 1996). Theories about ► metacognition are therefore central to understanding independent learning. Increasing attention is given in the literature to learning how to learn, which puts the emphasis on learners themselves understanding how they learn, reflecting on their learning and evaluating the outcomes. Independent learning draws from ► constructivist theories that suggest that knowledge is created by the learner rather than being imparted or transferred. Learners need to understand how they are constructing their learning in order to reuse and apply their cognitive processes in new circumstances. The quality of the learning is dependent on the learner's ability to direct his own learning and continually construct and reconstruct his thinking. It also depends on the learner's ability to self-evaluate whether learning outcomes have been successfully achieved and reflect on his own learning in order to adapt and further develop his learning.

The theoretical background of independent learning is shared with other similar concepts. For example, concepts such as "► self-regulated learning" and "► self-directed learning" are often described in similar ways to independent learning. Although proponents of these different concepts might not agree on a common definition, there are many shared assumptions about learners and the learning process. All three concepts involve personal agency and require active involvement, motivation, and intentionality by the individual learner. The concept of self-regulation appears to align most closely with independent learning. For example, Pintrich (2000, p. 453) defines self-regulation as "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment." The similarities to independent learning are also evident in Pintrich's description of the processes of learning. According to him, the processes of self-regulation are organized in four phases – planning, self-monitoring, control, and evaluation. These phases involve internal and external factors which Pintrich describes as cognitive, motivational/affective, behavioral, and contextual.

These phases highlight the need for independent learners to not only have cognitive and metacognitive skills but they must also believe that they are capable of using these skills to reach their learning outcomes. Therefore, learner motivation is a particularly important affective skill for independent learning. It has also been described as an outcome of independent learning. It is suggested that learners experience a sense of self-efficacy when they take responsibly for and feel in control of their own learning. Zimmerman's (2002) view is that self-regulated learners perceive themselves to be competent, self-efficacious, and independent. The importance of motivation draws on

Bandura's (1986, cited in Bandura 2001) ▶ social cognitive theory which considers the motivational and cognitive dimensions of learning.

Important Scientific Research and Open Questions

The variety of terms which describe similar learning processes to independent learning (self-regulated learning, self-directed learning, active learning, and student-centered learning) can result in confusion about the definition of independent learning. There is also a lack of clarity about how the definitions of these different concepts and their associated theories of learning relate to one another. Accepting that all the concepts are the same or similar reduces discussion about the differences and/or overlaps between the meanings of each and limits the possibility of each concept adding to understanding and developing theories of self-learning.

Questions arise about whether all learners are capable of learning independently and whether a certain level of cognitive skill is required before independent learning is possible. Zimmerman (2002) says that even high-ability learners may not achieve optimally because they are not able to use or control context specific cognitive and affective learning processes. These questions lead to further questions about how learners should be supported in order to help them develop as independent learners. Zimmerman's view suggests that learners do not necessarily become independent learners themselves. The learning process and the learning environment need to be structured in such a way that they enable learners to practice the skills needed, apply them in different circumstances and self-evaluate the outcomes. This has implications for both "learner and teacher readiness" for independent learning processes (Livingston et al. 2004). Teachers need to be willing and have the skills to change the way they relate to learners, organize the learning environment, and assess the learning outcomes in order to make the shift from teacher-led learning to student-led learning. This raises questions about teacher identity and beliefs about how learners learn effectively. Similarly, a key condition for success is student readiness for independent learning approaches. Students hold assumptions and have expectations about how they learn and about what teachers should do in the classroom. Changing deeply held views about learning and teaching to enable independent learning is challenging for both learners and teachers.

A lack of understanding about how to support the development of independent learning could lead to some teachers leaving learners unsupported, in the misbelieve that they should do nothing while a learner is engaged in an independent learning task. This highlights the need for teachers to understand the pedagogical implications of developing independent learners and the importance of structuring the environment to enable increasing learner independence. For example, a learning experience may be constructed by the learner according to his own learning needs with some regulation of learning by a teacher until such times that the learner has all the competences to be fully independent – with enough self-belief and self-confidence to be able to self-regulate, self-direct, and self-assess the learning outcomes. This requires teachers to understand how and when to ▶ scaffold the learner's learning process.

To assist teachers in understanding more about how to support independent learners, further research is needed to clarify whether the skills necessary for independent learning are subject specific or whether they can be transferred across subjects. This highlights the need for better understanding about whether the development of independent learning requires a whole-school approach so that learners have opportunities to transfer and test new skills in different situations.

Short term results of independent learning may be less successful than teacher-led learning which may raise doubts in the minds of the learners and the teachers about its effectiveness and may impact on both learner and teacher willingness to change approaches to learning. There are challenges in overcoming these doubts as the evidence of the effectiveness of independent learning may not be available until sometime in the future when new "learning-to-learn" skills can be applied in a different context successfully. Furthermore, it may be difficult, if not impossible to separate learning gains due to independent learning from gains made due to other factors. This indicates the need for further research in assessment of independent learning approaches and outcomes.

Increasing accountability for improving learning outcomes may add to the difficulty in encouraging teachers to change their learning and teaching methods. Some countries continue to have prescriptive curricula with the emphasis on summative assessment and may make it appear challenging for some teachers to promote independent learning in their classrooms.

Cross-References

► Active Learning
► Scaffolding Discovery Learning Spaces
► Self-Organized Learning

References

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology, 52*(1), 1–26.

Bruner, J. (1996). *The culture of education.* Cambridge, MA: Harvard University Press.

Livingston, K., Soden, R., & Kirkwood, M. (2004). *Post-16 pedagogy and thinking skills: An evaluation.* London: Learning and Skills Research Centre.

Meyer, B., Haywood, N., Sachdev, D., & Faraday, S. (2008) *Independent Learning: Literature Review* (Research Rep. No. DCSF-RR051). London: Learning and Skills Network.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451–502). San Diego: Academic.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into Practice, 41*(2), 64–72.

Individual Differences

Ali Simsek
Institute of Communication Sciences,
Anadolu University, Eskisehir, Turkey

Synonyms

Learner characteristics; Personal attributes; Student traits

Definition

Individual differences can be defined as personal characteristics that distinguish learners from each other in the teaching and learning processes. Learners are unique individuals who bring a critical set of variables to each learning situation, including delicate traits as indicators of their potential and the history of achievement as signs of previous accomplishments and predictors of future performance.

Theoretical Background

There are a number of individual differences that affect performance and attitudes of learners during teaching and learning. The most common differences of learners are gender, age, intelligence, ability, interest, prior knowledge, learning style, motivation, locus of control, self-efficacy, and epistemological beliefs (Kuzgun and Deryakulu 2004).

Gender is not only about biological sex of learners. It is more of social perceptions, attributions, sensitivities, and treatments of one's sex in a certain cultural context. In educational practice, it is about differences between male and female learners that affect their achievement, interaction, motivation, and attitudes in the teaching and learning process. It also includes how educators treat learners differently during instruction due to their genders.

Age creates certain psychological needs in a particular age-group. Children have different developmental characteristics than youngsters and adults. Instruction should meet desires, expectations, and wishes of learners in whatever the age-group they represent. When this is done properly and adequately, learners will be satisfied; if not, however, they will not enjoy their learning experiences and experience boredom.

Intelligence is usually considered the mental power of learning that reflects the sharpness of sensing, reasoning, and comprehending. Intelligence may affect both pace and amount of learning in a particular domain. In the past, intelligence used to be discussed as a general aptitude. In recent years, the concept of multiple intelligences has been popular among educators. The difference between these two orientations is that the understanding of general intelligence assumes that each learner has a different level of intelligence and this has an impact on his/her learning of a domain. The concept of multiple intelligences, on the other hand, assumes that the learner may be intelligent in more than one domain so that instruction should support him/her in as many domains as possible. Multiple intelligences are listed as linguistic (words), mathematical (numbers), spatial (pictures), kinesthetic (body), musical (rhythm), interpersonal (people), intrapersonal (self), and naturalist (nature).

Ability is the capability that is necessary for success on a similar group of tasks. It is often confused with the concept of intelligence. Ability is usually considered the functional part of intelligence developed through education. Two types of theoretical orientations in terms of ability have been offered as counter views. The orientation of general ability claims that there is a single type of ability which permits or limits one's learning in all domains. The orientation of specific abilities, in contrast, posits that each learner is able to learn faster and better in certain domains (e.g., verbal learning), whereas another learner may be more capable in other domains (e.g., spatial learning). Thus, each learner should be provided with more appropriate opportunities in the areas where he/she has better aptitude.

Interest can be defined as continued attention and natural tendency toward an object, situation, task, or activity. In other words, it is internal and spontaneous orientation toward something that the individual observes, pays attention, thinks about, and enjoys without any external stimuli. Interest is usually accompanied with pleasure, perseverance, and even dedication. Learners may have a variety of interests such as interests of science, engineering, communication, social service, literature, music, arts, history, foreign languages, sports, etc. It is better to accommodate these interests in order to support effective and appealing learning. For example, a learner who has difficulty in acquiring new vocabulary, may demonstrate great progress if he/she is given an opportunity to learn the names of animals or plants that he/she likes.

Prior knowledge: What do learners know about a particular topic before instruction begins. Learning usually occurs when links are established between prior knowledge and the new material. Therefore, the type and amount of prior knowledge of each learner should be assessed and taken into consideration before beginning to present new material. It is important to note that prior knowledge covers not only information but also perceptions, attitudes, and experiences about a new topic. Furthermore, prior knowledge may be incomplete, mistaken, obsolete, or irrelevant so that they should be corrected or updated before the actual instruction.

Learning style is a natural way of perceiving, interpreting, and evaluating the external stimuli. It is not a preferred way of learning because learning style is, to a great extent, an inherent characteristic. Of course, the environment may affect the formation of learning styles in the process of socialization, education, and enculturation. However, the learner cannot decide, select or control his/her learning style because it is almost automatic. There are different classifications of learning styles. The most common of them are: field dependent/field independent, accommodator/diverger/converger/assimilator, sharpener/leveler, and impulsive/reflector. Each instructional situation has learners with different styles so that instruction should be provided in such a way that everyone benefits from it.

Personality can be defined as organization of one's cognitive, affective, and physical characteristics that help him/her adjust to the environment in a unique way. Types of personality describe behavioral models and/or patterns of individuals. Introverted learners are usually busy with themselves and not very open to other people. In contrast, extraverted learners are open toward others and enjoy being with them. Similarly, introverted learners prefer to read from books and work alone, whereas extraverted learners would like to watch films and collaborate with other learners.

Motivation is affective power and effort toward accomplishing a task. The source of motivation can either be internal or external. Internal motivation exists when the learner tries to learn something for its own good. External motivation is often generated with external motives and incentives. Some learners find intrinsic value in learning new information so they demonstrate natural efforts without any expectation, while others expect encouragement and reinforcement to learn, thus the most common tools of external motivation are rewards.

Locus of control is about where the learner attributes his/her success and failures. Learners with internal locus of control attribute both success and failure to the self-related factors, while learners with external locus of control attribute success to themselves but failure to outside variables. In other words, those who have internal locus of control take personal responsibility about what they do or what happens to them, whereas learners with external locus of control usually complain about or blame other people, bad luck, unfairness, or inappropriate conditions as causes of events surrounding them.

Self-efficacy is the term that describes perceived beliefs about one's own capability of achieving a task or being successful in a particular area. Individual perceptions of a learner in terms of his/her chance for success differ from domain to domain. For example, a learner may believe that he/she is incompetent in mathematics but highly proficient in a foreign language. The implication is that he/she will try to do his/her best in the foreign language course but give up in mathematics. The reality may not prove his/her perception to be true so that, through education, each learner should be supported to develop an accurate self-efficacy.

Epistemological beliefs indicate personal thoughts of a learner about the nature of knowledge and the process of knowledge acquisition. Some learners may think that knowledge is simple and stable, while other learners may think that knowledge is complicated and variable. The learner who believes that knowledge is relatively stable in nature thinks that the truth is explained in available resources so that you go and get it. On the other hand, the learner who believes that knowledge constantly changes thinks that one should reach alternative sources of information in order to develop multiple perspectives on reality. Of course, these beliefs also affect the learner's amount of mental investment in learning.

Important Scientific Research and Open Questions

Although individual differences have long been an important issue in education, the current body of research is not strong enough to reach generalizations. There is no single study addressing all individual differences in education. Each study usually focuses on certain aspects of individual differences so that the results can only be interpreted within their own contexts. Generally speaking, however, the existing research implies that educational practices should be designed and conducted in such a way that individual differences should be accommodated in order to support the self-actualization process of learners (Buss and Greiling 1999).

The research has also demonstrated that learners differ to a great degree on each individual difference. There are various subcategories, known as types, within each individual difference. In other words, learners do not differ only in terms of individual differences such as aptitude, learning style, self-efficacy, etc., but also within each individual difference.

No subcategory of an individual difference is better than others. The learners are simply different rather than better or worse compared to each other. Assessment of some individual differences scores the performance of learners on a predetermined scale; however, this doesn't mean that the position of learners receiving high scores is more acceptable than the position of others. It is simply used for determining to which subcategory each learner belongs to. Then, characteristics of relevant subcategory are attributed to or assumed to exist in all learners who fall in the same category (Maltby et al. 2007).

Individual differences are qualitative in nature. It means that it doesn't make much sense to talk about the amount or level of a particular individual difference. Learners are either in one subcategory or in another, rather than being in one subcategory to a certain degree and in another to a different degree. Each learner is assigned to a different subcategory based on the results of assessment. For example, as far as learning style is concerned, an individual is categorized either as field dependent or field independent. We don't say that this individual is 25% field dependent and 75% field independent.

The assessment of individual differences employs one of the two approaches. An individual difference is measured either based on self-report or actual performance. Some measurement techniques ask learners how they perceive, feel, think, learn, or act. Then, they report their own situations to their best knowledge. The second group of measurement techniques, however, tries to assess individual performance of each learner on a test-like situation. Either group of techniques has its strengths and weaknesses so that appropriate ways of determining individual differences depend on purposes of assessment and possible uses of results.

Some of the individual differences are still treated as psychological constructs, not much of an educational variable. Theories and studies in psychology describe characteristics of individual differences. However, the evidence presented in terms of how these differences should be taken into account in teaching and learning processes is not addressed sufficiently. Thus, instructional theories should clarify implications of individual differences for teaching and learning so that more practical approaches should be developed.

Cross-References

► Abilities to Learn: Cognitive Abilities
► Abnormal Avoidance Learning
► Interests and Learning
► Learning Style(s)

► Multiple Intelligences and Learning Styles
► Religiosity and Personality
► Self-Efficacy and Learning

References

Buss, D. M., & Greiling, H. (1999). Adaptive individual differences. *Journal of Personality, 67*, 209–243.
Kuzgun, Y., & Deryakulu, D. (Eds.). (2004). *Egitimde bireysel farkliliklar [Individual differences in education]*. Ankara: Nobel.
Maltby, J., Day, L., & Macaskill, A. (2007). *Personality, individual differences and intelligence*. London: Pearson Education.

Individual Differences and Learning

► Ability Determinants of Complex Skill Acquisition

Individual Improvement

► Individual Learning

Individual Learning

Marco Novarese
Centre for Cognitive Economics – Dipartimento di Scienze Giuridiche ed Economiche, Università del Piemonte Orientale Amedeo Avogadro, Alessandria, Italy

Synonyms

Acquisition of knowledge; Building experience; Individual improvement

Definition

Individual learning is a process involving a change in agent's behavior or knowledge. So it determines a difference between a first and a second moment. Agent can learn a new information, or find a new strategy or develop a different representation of a situation. It might be the result of experience, reflection, trial and error, imitation, formal teaching, and it might be conscious or tacit. The change may make the agent more adapted to its environment or more capable of performing a task or just even more conscious of some realities. In such cases, learning implies an improvement as it allows better performances and decisions, or understandings. Usually this expression is, in fact, used as a synonymous of individual improvement. Yet, more generally (and especially in Psychology) individual learning has to be meant as a simple change between two moments, like in the case in which it determines a change in personal preferences or when a new habit is acquired.

In some cases learning can be seen as an increase in what we know. In other cases, it determines a substitution of part of some elements of individual knowledge. Both these processes may imply more or less stable changes (I can acquire new skills and later lose them).

Learning happens when changes aren't innate, or cannot be explained by natural processes of growth or by fatigue. Changes due to maturation are universal among all agents within a species; on the contrary changes caused by learning differ among individuals. Therefore learning implies some kind of individual difference.

The indo-european root of the English world ("leis") has also the meaning of "to pursue" or "to furrow," suggesting the need to follow a path. Learning has to be seen as a continuous process; humans do not learn once and forever, but they need to pursue knowledge throughout their life. Yet, following a furrow implies to be conditioned by the undertaken path.

Theoretical Background

Greek philosophers already discussed learning, when reasoning about pedagogy. Socrates developed his dialectic method aimed at allowing each person to understand her/his own truth, stimulating an individual research and avoiding any general dogma. This research is personal, but it can be helped by a master. A similar idea drives some contemporary training programs aimed at developing individual critical capacities (while it is not good when learner should acquire notions).

Aristotle evidenced two main different ways for learning: reasoning (the reflection on the causes of things) and experience ("Anything that we have to learn to do we learn by the actual doing of it . . . We become just by doing just acts, temperate by doing temperate ones, brave by doing brave ones" from the

"Niconachean Ethics," Book II, p. 91). So the specific acts we are used to determine our being. If we are used (for example because of our State's laws) to make just choices, we become just persons.

Individual learning played a central role in the analysis on the causes of the wealth of Nations, by Adam Smith, a moral philosopher considered the founder of Economics. He proposed the division of labor as the main cause of improvement of productivity, which was determined, among others factors, by the increased dexterity allowed by specialization and its related continuous specific training. Differences in natural talent among persons were seen mainly as the effect (and not the cause) of the division of labor. Many following studies on the determinants of capacities confirmed his intuition. Often talent is seen as an inborn quality. On the contrary, in many cases capacities seem to be mainly the product of intense and specific training (see Colvin Geoff 2008 for a non specialist but complete analysis).

When Psychology developed as a specific discipline, learning became one of its main, if not the main, subjects. To make psychology a real science, all unobservable mental phenomena had to be led apart, while focusing on real actions. Two main categories of learning where proposed: classical (or respondent) and operant conditioning, both focusing on association and reinforcement. Classical conditioning was first studied by Ivan Pavlov, a Russian physiologist, at the beginning of the twentieth century. He taught his dogs to salivate, when hearing the sound of a bell. At first, this conditioning was unplanned, as Pavlov just used to sound a buzzer before serving food. He observed his dogs salivating, as they associated the sound with food arrival. He then started to test more effects, like extinction (when a dog unlearned the association) or generalization (when a dog was taught to salivate when hearing even a partially different stimulus). Skinner gave another fundamental contribute. In his experiments, rats learnt to perform an action (like pressing a specific lever), in order to get food. Learning occurred as some actions were positively reinforced, through their association with a reward (whose desire was the internal stimulus for our agent). There was a negative conditioning when touching a lever determined a negative reward (like an electric shock).

Both the tendency to avoid a punishment and to search for rewards are adaptive capacities as they improve an animal's fitness to its environment. This mechanism is at work in many everyday situations: animals are trained to dance using prizes, but also children can be taught of avoiding bad behaviors by associating them with punishment. This mechanism links individual and social learning too. Imagine a child who has to learn how to behave appropriately in a social situation. She can perform two actions, A or B. A is the socially accepted convention, while B is the rude choice. When choosing A, she is rewarded, while she is blamed in the opposite situation. Positive and negative reinforcements stimulate individuals to perform the conventional action.

This kind of learning is highly mechanical and it's not deemed able to account for the development of all human (or even animal) capacities and knowledge. Even as a pedagogical device this model is inadequate: conditioning determines just a tendency to react to a signal, without a real understanding of what is going on. Besides, it requires fixed contexts, where agents can find out a stable link between a cause and an effect. Reinforcement learning requires also a clear and immediate feedback, which is not always available.

When learning takes place in a stable and fixed environment, with a clear feedback, agents can always understand the best strategies. In this case it allows to improve performance and can even be seen as the source of rational behavior, as in many Economics models. Yet, a growing literature is showing the existence of the so called "traps of learning." As an example, the managerial literature found out managers tend to perform strategies that proved successful in the past, even when environment changed, calling for new actions. This happens because feedback is not always clear and immediate and because contexts change.

The relevance of contexts was evidenced by Gregory Bateson (1972) in his wide analysis. He proposed a multi-steps representation of this mechanism. A first, zero, level happens with the simple acquisition of information: student learns from the clock that it is eight o'clock and he must go to school. His behavior changes, but there is no evolution in his strategy; he simply uses the new information according to an already developed model of action. Learning I happens when a new association is developed, as in the operant or classical conditioning. After their training, Pavlov's dogs behaved differently than before. This process is usually adaptive and links individuals with their environment. In order to learn, Pavlov's dogs fix some elements in the situations faced, considering the laboratory as a specific context and excluding all external information (so the link between the bell and the food is independent from the wheatear). If every experience were perceived as new, in fact, there could be no learning and it would be impossible to gain knowledge from the past. So, at the same time, agents should find out how to recognize a context and understand an association which takes place within such a domain. Learning, therefore, requires also the capacity to recognize when a rule can be applied.

A dog trained in Pavlov's laboratory undertakes different levels of training. Apart from the specific association between bell and food, in fact, it also learns to expect a sign before food is served. If this dog is transferred to a new laboratory, where food is served after, say, a lamp is light, according to Bateson, it will learn faster to salivate when the new signal is displayed. All animals tend, in fact, to look for situations already experienced, that is to look for a specific kind of conditioning. While Pavlov's dogs learn to wait for the food, expecting a signal of its arrival, without any chance to influence this event, rats trained by Skinner, on the contrary, develop the attitude to search for the rewarded action. This attitude defines the second step of learning. Experience, therefore, affects also the way we look at the reality, and so even our individual traits: a child who is usually rewarded when doing what her parents require, undertakes a training similar to that of a Skinner's rat. She will tend to search for the rewarded action in all new situations faced. Yet, this attitude is not necessarily useful, as new environments can be different from previous ones. Learning II, therefore, can help or slow learning I according to the similarity among situations. A third step, highly difficult, is learning how to undertake learning II, and it could allow individuals to manage learning II and reduce conditioning from the past.

Learning is also a way to reduce perceived uncertainty. A completely new situation can be scaring. The Wundt curve measures how people enjoy an experience in relation to the level of novelty they perceive in it. A complete lack of novelty is bad and boring, but too much novelty is too uncertain and therefore painful (Scitovsky 1976). Experience and the capacity to find similarities between past and present are necessary to enjoy goods and deal with uncertain situations. Individual differences will determine heterogeneous attitudes.

Chase and Simon (1973) related learning and perception. Studying how chess players behave during a game, they noticed that experts see the board in a different way from novices. So instead of having to remember and process the position of many pieces, experts look at their overall configurations, relating it to the ones they previously faced. The more experience a player has, the wider set of past configurations her memory holds. Learning can be seen here as the capacity to create and remember configurations of pieces so to have more manageable unit of information. As an example, consider a person who has to remember a series or letters, like r, t, y, u .... Her task would be easier if instead of having to recall individual letters, she had to remember words, that is, a meaningful collections of letters, already known. The process of building configurations is called chunking and determines how we perceive reality and our capacity to deal with it. In this sense, therefore, learning does not simply imply the acquisition of new data, but it represents the way we build our perception of reality.

Important Scientific Research and Open Questions

There are many open questions on this subject. As persons learn in social contexts, how is individual learning different from social one? From a different perspective: if learning is individual, how can agents develop social knowledge?

If learning can be seen as a mechanism leading agents to select some specific information, a crucial point in order to understand human rationality is how such information is selected. Are we able to select the most relevant one? And how does this affect our capacity to evaluate situations?

We need to understand the relation between learning, experience, and rationality. This is a crucial point as it determines how science, management, and politics represent human actions with many philosophical but also practical implications (see Novarese 2008).

Cross-References

- ► Abstraction in Learning
- ► Adaptive Learning
- ► Bateson, Gregory
- ► Chunking/Chunks
- ► Conditioning
- ► Context-Based Learning

► Feedback and Learning
► Pavlov, Ivan P. (1849–1936)
► Skinner, Burrhus Frederic (1904–1990)
► Social Learning

References

Bateson, G. (1972). *Steps toward an ecology of mind.* New York: Ballantine Books.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology, 4*, 55–81.

Colvin, G. (2008). *Talent is overrated: What really separates world-class performers from everybody else.* London: Nicholas Brealey Publishing Ltd.

Novarese, M. (2008). Is bounded rationality a capacity, enabling learning?. Economics and Econometrics Research Institute research paper series, 12. http://ideas.repec.org/p/eei/rpaper/eeri_rp_2009_12.html. Accessed 22 April 2011.

Scitovsky, T. (1976). *The joyless economy: The psychology of human satisfaction.* Oxford: Oxford University Press.

Further Reading

Smith, A. (1776). *An inquiry into the nature and causes of the wealth of nations.* Chicago: University Of Chicago Press.

Individual Learning Procsses

Each decision made by individuals is a test of one's knowledge, which refers to situational dynamics. What one does at any point in time depends on one's knowledge at that time, and on the logic of the situation in which that knowledge is used. Behavioural changes result from changes in one's knowledge as well as from intended or unintended changes in one's situation (Boisot et al. 2007). Defining learning processes benefits from the distinction between two competitive theories of knowledge: the "bucket" versus the "searchlight" theories of knowledge. This distinction has been introduced by Karl Popper and is analysed in Boland and Fowler (2000). In the "bucket" theory of knowledge, individual learning processes are nothing but an accumulation of data and "raw" experience. Knowledge acquisition is nothing but adding to one's bucket (therefore its name) on the grounds that the more observations one makes, the more knowledge one has. It is also related to beliefs about inductive logic and proofs. The "searchlight" theory of knowledge conversely focuses on the use of knowledge in society, and on the relevance of available knowledge against specific situations. One introduces assumptions (conjectures) about the real world, and learns when improving (rather than increasing) knowledge. Learning is always a negative experience, one of refuting prior claims. Decision making is a process and not an event.

References

Boisot, M. H., et al. (2007). *Explorations in information space.* Oxford: Oxford University Press.

Boland, T., & Fowler, A (2000). A systems perspective of performance management in public sector organization. *International Journal of Public Sector Management, 13*(5), 417–446.

Individual-Based Modeling

► Agent-Based Modeling

Individualized Education Plan (IEP)

► Alignment of Learning, Teaching, and Assessment

Individualized Instruction

► Open Instruction and Learning

Individualized Learning

► Personalized Learning

Induction

► Generalization Versus Discrimination

Induction and Abduction

► Multistrategy Learning

I

Inductive Learning Spatial Attention

Paulo E. Santos
Departamento de Engenharia Elétrica, Centro Universitário da FEI, S. Paulo, Brazil

Synonyms

Learning protocols; Visual perceptual learning

Definition

We call inductive learning spatial attention the process whereby a computer vision system automatically induces the focus of attention from the visual observation of patterns in space. In their most basic form, these patterns of space are formed by colored blocks that are stacked in order to create repetitive sequences of colors. The observation of such patterns is fed into an inductive logic programming system that generates a model of expectancy about the next block to be placed in the sequence.

Theoretical Background

The idea of inductive learning was first proposed by C.S. Peirce in the nineteenth century (Hartshorne et al. 1956). However, the computational application of induction to automatically learn patterns in space from a computer vision system was introduced in Needham et al. (2005). In this work, the behavior of a player engaged in a card game was learned using inductive logic programming (cf. (Muggleton 1996)) from the visual observation of a number of game turns. Based on this work, the idea of inducing the focus of attention by observing patterns in space was defined in Santos et al. (2008) as a system composed of the following three procedures:

- A data-driven visual attention
- A statistically learned spatial attention
- A symbolically learned spatial attention

The task of the *data-driven visual attention* is, from computational manipulation at the image level, to direct the viewpoint (the video camera) to follow salient objects in the observed scene. This process can be broadly divided into four components:

1. Bottom-up color and motion saliency: at this step the whole image is processed
2. Figure-ground operations: incorporates some top-down biases that are applied only at the focus of attention provided by the step 1 above, in order to segment the salient objects from the background scene
3. Active tracking: tracks the salient object picked out by the figure-ground operations
4. Marker tracking: maintains a short-term memory of interesting locations for the salient objects

At the *statistically learned spatial attention* level a probability density function, in the form of a particle distribution of prototype vectors, is learned using an unsupervised neural network. This is used to direct the focus of attention to places where objects are expected to be, given previous observations.

Finally, the *symbolically learned spatial attention* uses inductive logic programming to learn patterns in space formed by object positions and colors. For instance, if the system observes a human agent building a tower of colored blocks defining a repetitive pattern of colors (e.g., two white blocks always on top of a single black block), the symbolic learning finds a set of rules with which a synthetic agent can predict the next block on the tower and its position on top of it.

Important Scientific Research and Open Questions

There is a long track of research in artificial intelligence on the combination of two visual processes: bottom-up (where scene features are extracted from pixels in the image) and top-down (where a conceptual–symbolic level guides the image processing) (Tsotsos et al. 1980). However, only recently machine learning methods have been applied at the conceptual level in this context (Needham et al. 2005). Investigation on inductive learning spatial attention aims the application of these ideas to guide one of the most preliminary stages of visual processing: the focus of attention. Not only does this research allow a better understanding of the relationship between bottom-up procedures and top-down reasoning, but it also instigates investigation on learning general symbolic information (such as abstractions, analogies, and high-level theories) from visual data. An initial step in this direction was taken in Santos et al. (2004) that reports results of inducing the axioms of equality and linear order from the visual observation of simple dice games.

The investigation of inductive learning spatial attention on more challenging scenarios, including, for instance, the induction of spatial attention for a mobile agent in a dynamic environment, is an important open problem for future research.

Cross-References

► Action Learning
► Attention and the Processing of Visual Scenes
► Inductive Logic Programming
► Learning from Video
► Learning Spatial Orientation
► Perceptual Learning
► Rule Learning
► Spatial Learning
► Visual Perception Learning

References

Hartshorne, C., Weiss, P., & Burks, A. W. (Eds.). (1956). *Collected papers of Charles Sanders Peirce* (Vol. 8). Cambridge, MA: Harvard University Press.

Muggleton, S. (1996). Learning from positive data. In S. Muggleton (Ed.), ILP96, Vol. 1314 of Lecture Notes of artificial Intelligence, SV (pp. 358–376).

Needham, C., Santos, P. E., Magee, D., Devin, V., Hogg, D., & Cohn, A. G. (2005). Protocols from perceptual observations. *Artificial Intelligence Journal, 167*, 103–136.

Santos, P. E., Magee, D., Cohn, A. G., & Hogg, D. (2004). Combining multiple answers for learning mathematical structures from visual observation, Proceedings of the European conference on artificial intelligence (ECAI-04), Valencia, Sp.

Santos, P. E., Needham, C., & Magee, D. (2008). Inductive learning spatial attention. *Sba Controle & Automação* (Vol.19, No. 3, pp. 316–326). ISSN: 0103-1759. doi: 10.1590/S0103-17592008000300007.

Tsotsos, J., Mylopoulos, J., Covvey, H. D., & Zucker, S. W. (1980). A framework forvisual motion understanding. IEEE Pattern Analysis and Machine Intelligence, pages 563–573. Special Issue on Computer Analysis of Time-Varying Imagery.

Inductive Logic Programming

Filip Železný
Czech Technical University in Prague,
Prague 6, Czech Republic

Synonyms

Logic-based relational machine learning

Definition

Inductive Logic Programming (ILP) (De Raedt 2008; Nienhuys-Cheng and De Wolf 1997) is a family of methods for automated learning (or machine learning) of general rules from specific data and background knowledge. Unlike other machine learning methods, ILP uses the expressive language of the first-order predicate logic to represent input data, background knowledge, and learned hypotheses. This makes ILP suitable for data mining applications in domains characterized by nontrivially structured data, such as biochemistry or natural language processing. Since learned hypotheses can acquire the form of logic programs, the goal of ILP may be formulated as automated induction of the latter; hence, the name inductive logic programming.

Theoretical Background

Consider a task where an ILP algorithm receives examples of toxic and nontoxic chemical compounds. From these examples, it learns a general hypothesis, according to which toxicity of new compounds may be predicted. Here, each learning example describes a compound. The description may enumerate all atoms in it, all bonds between pairs of atoms, and selected properties of the atoms and the bonds. The structure of a compound is thus represented as a collection of basic elements (atoms) and their relations (bonds). Due to this relational nature of considered data, ILP is often referred to as a relational machine learning paradigm.

Each learning example is classified as toxic or nontoxic. The former are thus positive examples of the toxicity concept and the latter are negative examples of it. The main goal of an ILP algorithm is then to produce a hypothesis according to which all positive examples would be classified as toxic (i.e., the hypothesis is complete) and all negative examples would be classified as nontoxic (i.e., the hypothesis is consistent). Encoded in a suitable logic syntax, the hypothesis will likely condition toxicity on the presence of certain atoms and bonds within the structure of the compound in question.

Assume further that prior to learning, the chemical concept of an *aromatic ring* is considered relevant to prediction of toxicity. Such a concept may be described through a logical assertion stipulating the configurations of atoms and bonds that indeed constitute aromatic rings. Accounting for such background knowledge, an ILP algorithm should output a hypothesis which, in conjunction with that background knowledge, is complete and consistent with respect to the learning examples. Such a hypothesis might for instance assert that a compound is toxic if it contains an aromatic ring and a specific group of atoms bonded to that ring.

Correctness (i.e., completeness and consistency) of the resulting hypothesis on the learning examples of course does not guarantee correct classification of other compounds. To estimate the accuracy of a learned hypothesis on new data or the number of learning examples needed to maintain accuracy high, techniques from the general field of machine learning may be employed. These can be both theoretical (such as error bounds derived in the PAC-learning context) and empirical (such as cross-validation).

Various ILP frameworks differ mainly by the choice of the logical constructs used to encode examples, and consequently by the computational procedures used for logical inference. The most popular framework is known as *learning from entailment.* Here, learning examples are first-order clauses such as the following clause e:

$$e = \mathrm{toxic}(\mathrm{c}) \leftarrow \mathrm{atom}(\mathrm{c}, \mathrm{a}_1, \mathrm{carbon}), \mathrm{atom}(\mathrm{c}, \mathrm{a}_2, \mathrm{oxygen}), \mathrm{bond}(\mathrm{a}_1, \mathrm{a}_2), \ldots$$

that is to be interpreted as "compound c is toxic as a result of its structure containing a carbon atom connected to an oxygen atom, (etc.)". A hypothesis is a set of clauses (so-called clausal theory). If e above is a positive example, then we ask that the produced hypothesis logically entails e. For example, the single-clause hypothesis H

$$H = \forall C, A : \mathrm{toxic}(C) \leftarrow \mathrm{atom}(C, A, \mathrm{carbon})$$

expressing that any compound containing a carbon atom is toxic is clearly a more general (stronger) statement than e and thus logically entails it. This is denoted as $H \models e$.

Background knowledge B is also a set of clauses. For example, the background knowledge rule described informally earlier would consist of clauses such as

$$B = \mathrm{aromatic\_ring}(C_1, C_2, \ldots, C_6) \leftarrow \mathrm{atom}(C_1, \mathrm{carbon}), \ldots$$

each describing a possible configuration of atoms in an aromatic ring. This may then be employed by the ILP algorithm by plugging the condition aromatic_ring $(C_1, C_2, \ldots, C_6)$ in the right-hand side of H.

In summary, the goal of learning from entailment is formalized as follows. The algorithm receives a set E^+ of clauses (positive examples), a set E^- of clauses (negative examples), and a clausal theory B (background knowledge). It is asked to output a clausal theory H (hypothesis) such that $H \cap B \models e$ for all (or as many as possible) $e \in E^+$ and no (or as few as possible) $e \in E^-$.

To produce the desired theory, most ILP systems systematically search a space of clauses to find a clause that does not entail a negative example and entails some positive examples, though possibly not all of them. The entailed positive examples are then removed, and a new clause is searched for the remaining examples. After a finite number of such iterations, a complete and consistent theory is eventually assembled from the found clauses.

The relation $\models$ forms the mathematical structure known as a *lattice* on the space of clauses. More precisely, since two different clauses C_1 and C_2 may be equivalent in that simultaneously $C_1 \models C_2$ and $C_2 \models C_1$, the lattice is defined on the clause *equivalence classes.* If background knowledge B is empty, the straightforward way to search a single clause would be to traverse this lattice, using some conventional search strategy such as *branch and bound.* The function optimized by the search is computed from the counts of positive and negative examples entailed by the currently inspected clause. These counts are monotone under the entailment relation, enabling the use of search techniques such as pruning. However, the relation $C_1 \models C_2$ between two clauses is generally undecidable and thus is usually approximated by another relation known as θ-subsumption. The latter is verified by syntactical inspection of the clauses. While decidable, it is computationally difficult (NP-complete) and thus is often again approximated by efficiently computable relations. In effect, the lattice defined by entailment is only approximated by the lattice actually searched. If B is nonempty, one should search a clause lattice defined by entailment relative to B i.e., by the relation $B \cap C_1 \models C_2$ between clauses C_1 and C_2. θ-subsumption-based approximations to this relation are only available under rather strict assumptions on the form of B.

Besides entailment checking, another complexity concern follows from the often unmanageable size of the search lattice. To this end, ILP systems impose restrictions on the syntactic form of learned hypotheses, thus reducing the size of the lattice. A widely adopted, though usually not a sufficient, condition is that hypotheses consist only of *Horn* clauses. A Horn clause has at most one literal to the left of the implication sign, as in all the clauses shown above. Such hypotheses correspond to *logic programs*. Due to the presence of both the *machine learning* and *logic programming* ingredients, ILP is referred to as the intersection of the two mentioned fields.

Applications

ILP has found applications mainly in analysis and modeling of nontrivially structured data in domains including biochemistry (prediction of mutagenicity of compounds), molecular biology (prediction of protein secondary structure, completion of metabolic pathways), ecology (prediction of biodegradability), engineering (finite element mesh design), or natural language processing (word sense disambiguation).

One of the most prominent applications of ILP was demonstrated within the *robot-scientist* project (Muggleton 2006). Here, a robot was devised to automatically propose and validate scientific hypotheses in functional genomics by using machine learning and by physically conducting laboratory experiments. The robot used ILP techniques to discover key molecular substructures within a class of potential cancer-producing agents and to select experiments that would discriminate between contending hypotheses.

Important Scientific Research and Open Questions

While conventional ILP provides excellent means for representing complicated relational structures discovered in data, its crisp logical foundations do not allow to elegantly deal with uncertainty inherent to most real-life data sets. For example, in the earlier mentioned chemical domain, a learned clausal theory deems any given compound either to be toxic or nontoxic. In real-life applications, however, it would be desirable to learn theories that would estimate the probability of the compound being toxic. One the most pressing challenges in current ILP research is thus to combine the rich logic formalism of ILP with statistical learning techniques. These efforts form a vivid discipline in the research field of *statistical relational learning*.

Current research issues also include the translation of ILP techniques to nonconventional logics (such as description logics popular in the semantic web), determining bridges between ILP and other forms of learning from structured data (such as graph mining techniques), devising fast clause-search algorithms (such as by using randomized search), or some long-standing open problems such as searching in the space of entire clausal theories rather than single clauses.

Acknowledgments

The author is supported by the project 103/10/1875 of the Czech Science Foundation.

Cross-References

► Constraint Satisfaction for Learning Hypotheses in Inductive Logic Programming
► Constructive Induction
► Ontology and Semantic Web
► PAC Learning
► Relational Learning
► Rule Learning
► Statistical Learning Theory and Induction

References

De Raedt, L. (2008). *Logical and relational learning*. Heidelberg: Springer.
Muggleton, S. H. (2006). Exceeding human limits. *Nature*, *440*(7083), 409–410.
Nienhuys-Cheng, S.-H., & De Wolf, R. (1997). *Foundations of Inductive Logic Programming*. Heidelberg: Springer.

Inductive Machine Learning

► Supervised Learning

Inductive Teaching

► Discovery Learning

Industrial Assembly Line Education

► Reproductive Learning

Infancy

► Infant Learning and Development

Infant Artificial Language Learning

Elizabeth Johnson, Marieke van Heugten
Department of Psychology, University of Toronto at Mississauga, Mississauga, ON, Canada

Synonyms

Miniature language; Nonsense language; Patterned syllable stream

Definition

Artificial languages are miniature languages purposely constructed by linguists and psychologists to test a specific hypothesis regarding the origins of language knowledge or language learnability. The phrase "infant artificial language learning" refers to a particular type of experimental paradigm in which infants are briefly exposed to an artificial language and then tested on their recognition of patterns or rules contained within that language. Unlike Esperanto or Klingon, the artificial languages used in infant studies are generally not designed for communicative purposes. Rather, they typically consist of a stream of carefully patterned but meaningless syllables. Due to their highly simplified nature, these artificial languages reflect only a select property (or set of properties) observed in natural languages. For example, a researcher interested in how infants start learning the sound structure of language might construct a language containing a lexicon full of words conforming to some predictable sound form template, but the words in the lexicon will have no meaning and the language will have no grammatical rules for stringing together words into longer multi-word utterances. In contrast, a researcher interested in the acquisition of the syntactic rules of language would need to include rules for stringing together words into longer utterances but may pay little attention to the sound form of the words in the language's artificial lexicon.

Theoretical Background

The debate over the role of nature versus nurture in the acquisition of language has always been a major point of contention for both linguists and psychologists. Historically, those who believed that nature must play a greater role than nurture have pointed to the complexities of language, arguing that children could not possibly use simple statistical (or associative) learning mechanisms to acquire the complex structure of human language. Those who believed that nurture must play the primary role in language acquisition, on the other hand, have argued that children's computational abilities are strong enough to deduce the structure of many aspects of language based on experience alone. According to this latter view, extensive innate linguistic knowledge is not needed to explain the speed with which children acquire their native tongue because the language they hear contains the distributional cues needed to work out many aspects of its underlying structure. It was not until the mid-1990s that experimental studies were able to shed some light on the debate over whether or not infants possessed learning mechanisms powerful enough to extract complex patterns from language input. In this now classic study, Saffran et al. (1996) demonstrated that 8-month-old infants could extract the statistical structure of an artificial language after a mere 2 min of exposure. Dozens of infant artificial language studies appeared in the literature soon thereafter, all revealing the power of infants' learning abilities (see Gómez and Gerken 2000, for review). In these studies, researchers created artificial languages containing simplified versions of patterns that exist in natural languages. If infants succeeded in extracting the targeted patterns from the simplified artificial language, researchers would argue that infants possessed the necessary skills to extract the similar (albeit admittedly more complex) patterns from natural language. The logic underlying these studies was that the more infants could learn based on experience alone, the less innate language knowledge they had to be endowed with in order to succeed in acquiring language. Note, however, that although evidence from artificial language learning experiments suggests that many aspects of language can be learned from experience, these findings have not typically been used to argue that all aspects of language can be learned. That is, the findings are not used to support a purely empiricist view on language acquisition. Rather, the goal of most artificial language learning experiments has been to determine what aspects of language could be learned from experience and how that learning might be constrained by built-in perceptual, cognitive, or linguistic biases.

Important Scientific Research and Open Questions

One of the greatest strengths of artificial language learning experiments is the tight control they allow the experimenter to have over the learning conditions experienced by an infant. This experimental control has enabled researchers to ask questions that would otherwise be impossible to address. For example, in the artificial language study by Saffran et al. (1996), 24 8-month-olds were tested on their recognition of syllable sequences that were defined by very precise statistical properties. The researcher knew exactly how many times the infant had been exposed to each particular syllable sequence that occurred in the miniature language. Short of recording and transcribing every utterance ever heard by each of a few dozen 8-month-olds (or better yet: have these children hear only an artificial language for the first 8 months of their life), it would be impossible to design anything even remotely resembling a natural language analogue to the Saffran et al. artificial language learning study. Thus, the beauty of an artificial language is that it puts the researcher in complete control of the input received by the child. Artificial language studies capitalizing on this capability have taught us a great deal about infant learning. For example, we have learned how infants' tracking of statistical dependencies between syllables changes over the course of development (e.g., Thiessen and Saffran 2003). We have also learned how infants might track statistical relationships in speech versus nonspeech stimuli (e.g., Marcus et al. 2007). And we have been able to explore how the phonological naturalness of an artificial language might interact with pattern learning (Seidl and Buckley 2005). However, despite everything that we have learned from artificial languages, there are still some open questions regarding the legitimacy of this methodology's use to study infant language acquisition. While the greatest strength of the artificial language paradigm is the absolute control it gives the researcher over the learning environment of the infant, this strength is unfortunately also this paradigm's greatest weakness since there is always a trade-off between experimental control and ecological validity in laboratory studies. That is, natural languages are far more complex than artificial languages. For example, unlike the artificial language used by Saffran et al., no natural language consists of just four trisyllabic words that all have identical syllable structure. Similarly, no natural language contains sound structure in the absence of meaning or syntax in the absence of sound structure. Given this lack of simplicity in natural languages, one may wonder whether it is a fair assumption that the rules and patterns infants learn from artificial language input will necessarily be the same type of rules and patterns infants extract from natural language input. In other words, will the learning mechanisms used in the laboratory necessarily scale up to the challenge of natural language? Could the learning strategies infants apply in an artificial language learning task differ qualitatively from those used in natural language acquisition? In recent years, researchers have started to address these questions. One approach has been to expose infants to slightly more complex languages and see whether infants succeed at pulling out the same rules and patterns that they pull out with less complex languages. Initial studies have suggested that learning may indeed break down in some cases when artificial languages are made slightly more complex (Johnson and Tyler 2010). An important line of research in the future will thus involve further exploring whether infant artificial language learning studies are too simplified (or artificial) to tap into the same learning processes involved in natural language acquisition.

In sum, it is clear that the large number of high-impact infant artificial language learning experiments published in the past 15 years have permanently altered theoretical views on early language acquisition. Even if the learning mechanisms infants apply to artificial languages are not exactly the same as those they apply to natural language, the fact remains that infants learn artificial languages with incredible ease and speed.

This finding by itself is enough to posit that infants may be capable of learning more aspects of language based on experience alone than most language researchers would have imagined possible before the advent of infant artificial language learning research.

Cross-References

- ▶ Acoustic and Phonological Learning
- ▶ Associative Learning
- ▶ Bayesian Learning
- ▶ Bootstrapping: How not to Learn
- ▶ Chunking Mechanisms and Learning
- ▶ Connectionism
- ▶ Infant Language Learning
- ▶ Infant Learning and Development
- ▶ Language Acquisition and Development
- ▶ Learnability
- ▶ Learning by Chunking
- ▶ Perceptual Learning in Speech
- ▶ Speech Perception and Learning

References

Gómez, R. L., & Gerken, L. A. (2000). Infant artificial language learning and language acquisition. *Trends in Cognitive Sciences, 4*, 178–186.

Johnson, E. K., & Tyler, M. (2010). Testing the limits of statistical learning for word segmentation. *Developmental Science, 13*, 339–345.

Marcus, G. F., Fernandes, K. J., & Johnson, S. P. (2007). Infant rule-learning facilitated by speech. *Psychological Science, 18*, 387–391.

Saffran, J., Aslin, R., & Newport, E. (1996). Statistical learning by 8-month-old infants. *Science, 274*, 1926–1928.

Seidl, A., & Buckley, E. (2005). On the learning of arbitrary phonological rules. *Language Learning and Development, 1*, 289–316.

Thiessen, E. D., & Saffran, J. R. (2003). When cues collide: Use of statistical and stress cues to word boundaries by 7- and 9-month-old infants. *Developmental Psychology, 39*, 706–716.

Infant Familiarization

▶ Habituation in Infant Cognition

Infant Habitual Action

▶ Sensorimotor Schema

Infant Language Acquisition

▶ Infant Language Learning

Infant Language Development

▶ Infant Language Learning

Infant Language Learning

Karen Mattock
Department of Psychology, Lancaster University, Lancaster, UK

Synonyms

Infant language acquisition; Infant language development; Language acquisition; Language development

Definition

Infant language learning refers to how young children (0–2 years) acquire knowledge about what sounds are in their language, how they learn where words begin and end in fluent speech and that words map on to referents in their environment, and how vocabulary (expressive and receptive) and sensitivity to syntactic forms (word order/sentence structure) is acquired.

Theoretical Background

There are a number of accounts of infant language learning that differ in terms of their emphasis on endogenous mechanisms, environmental influences, or a combination.

The notion that infants possess learning mechanisms that have evolved for language acquisition is the core of the domain-specific view of language learning held by nativists. Nativists argue that infants are born with a language-specific learning device whereby aspects of the formal structure of language are universal and innately specified internal representations specially dedicated to language learning. Key to nativist ideas is the argument that biological structures determine cognitive structures and that language input is too impoverished (and the infants' learning mechanisms too weak) to explain language acquisition.

Empiricists view the infant as a blank slate equipped with general ► associative learning (domain-general) mechanisms. They argue that language is learned through experience and external reinforcement and constrained by general learning mechanisms that are not special to the domain of language. For example, ► statistical learning, a domain-general learning mechanism available to infants early in life, can account for learning of speech sound categories, segmentation, word learning, and syntax.

Some ► constructivist theories posit that precursors to thinking and language are dependent on infants' action, perception, and imitation, and that language is built ► ontogenetically and adapted by an internal mechanism. However other ► constructivists view language as developing through socially mediated interaction. Other viable approaches to infant language learning are social-interactionist accounts that combine Nativist and Empiricist approaches to specify how cognitive and perceptual constraints allow infants to extract and detect regularity in the linguistic input to make form-function mappings (Lust and Foley 2004). Bootstrapping accounts of infant language learning also emphasize the learner's ability to detect patterns in the input that can assist in learning about higher-level linguistic organization, for example, using information in the input such as stress to help segment words from the speech stream (Jusczyk 1997).

Important Scientific Research and Open Questions

Understanding the influence of the language environment on infants' perception of phonetic contrasts has been important for informing how infants form phonetic categories. This research shows that at birth infants can discriminate between pairs of speech sounds from any of the world's languages, regardless of their language background, but by the end of the first year of life, they tune into those distinctions that are present in their native language and filter their attention away from nonnative phonetic contrasts (Polka et al. 2007). This attunement to the native language occurs as a function of age and increasing language experience. It is assumed that some form of perceptual ► distributional learning underlies phonetic category learning. In recent years, electrophysiological methods have been employed to study phonetic category learning in infants. Identifying the neural mechanisms underlying phonetic category learning is an open question, and reconciling the findings from behavioral studies and neurological studies presents new challenges.

Other lines of research have focused on understanding what cues infants use in order to segment words from fluent speech, and what constraints, mechanisms, and skills underlie word learning. Prosodic, phonotactic, allophonic, and statistical cues have all been found to play a role in word segmentation (Johnson and Jusczyk 2001). There are a number of proposals regarding how infants learn word-referent mappings. These include the notion that general attentional mechanisms are responsible and that tracking the statistical co-occurence of the word form and the referent are important. Other proposals emphasize the operation of lexical constraints such as mutual exclusivity, or highlight the role of socio-pragmatic cues. An open question relates to the links between the word learning process and general cognitive abilities, which have been raised but not extensively studied with infants.

Infants must also learn about categories of words, for example, whether words are determiners or nouns, and grammatical structure, for example, how words are ordered in sentences. Artificial language learning studies give insight into natural language processing, and highlight that there are distributional patterns in the input that are helpful for indicating grammatical structure. For example, when familiarized with strings from one of two grammars where strings are legal in one grammar but not the other, infants later recognize new strings from the familiar grammar, indicating that they can generalize knowledge of grammatical structure to new instances (Gomez and Gerken 1999). An open question is whether such learning mechanisms are really domain-general. It is argued that domain-general mechanisms are insufficient to explain language learning because nonhumans cannot learn language as well as humans. A potential avenue for future research is investigation of the neural basis of domain-general learning mechanisms.

Understanding the role of input in the language learning process, particularly in the acquisition of language structure, is an area of continued study and theoretical debate. The Nativist position is that input is inadequate for children to extract structure and that input has little influence on the process of language learning. Some challengers of this view argue that children learn grammar via communicative function and without innate knowledge. Others posit that language structure can be inferred from distributional or statistical patterns in the input via domain-general learning mechanisms. There are also those that view infant language learning as a complex interaction between the role of input and characteristics within the child, such as attention and memory (Polka et al. 2007).

Cross-References

- ► Language Acquisition and Development
- ► Speech Perception and Learning
- ► Statistical Learning Theory and Induction
- ► Word Learning

References

Gomez, R., & Gerken, L. A. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition, 70*, 109–135.

Johnson, E. K., & Jusczyk, P. W. (2001). Word segmentation by 8-month-olds. When speech cues count more than statistics. *Journal of Memory and Language, 44*, 548–567.

Jusczyk, P. W. (1997). *The discovery of spoken language.* Cambridge, MA: MIT Press.

Lust, B. C., & Foley, C. (2004). *First language acquisition: the essential readings.* Malden: Blackwell.

Polka, L., Rvachew, S., & Mattock, K. (2007). Experiential influences on speech perception and speech production in infancy. In E. Hoff & M. Shatz (Eds.), *Blackwell handbook of language development* (pp. 153–172). Oxford: Blackwell.

Infant Learning and Development

Melissa W. Clearfield
Department of Psychology, Whitman College, Walla Walla, WA, USA

Synonyms

Child development; Infancy

Definition

Infant learning and development reflect interactions among many variables across a number of levels and time scales. All of the contributing interactions are bi-directional and nonlinear. Development occurs at multiple levels within an individual, from cellular, molecular, and neural changes to increases in perceptual, motor, cognitive, social, and emotional abilities, and all of these are impacted by changes in society, culture, and historical era. Development also operates over multiple time scales, meaning some changes occur in a millisecond, while others take days, years, or generations, and the changes that occur at each of these time scales constantly interact with the changes occurring at the other time scales.

Theoretical Background

The central question of how infants develop is quite old, with roots in ancient Greece and early British philosophy. From its inception, the question was asked as a dichotomy, now known as the nature–nurture debate. The nature side posited that development is derived from within, meaning genetics or heredity. The nurture side posited that we are born as blank slates, and development is shaped by our experiences.

Throughout the twentieth century, developmental psychologists tried to find some common ground between the two sides of the debate. Piaget described distinct stages of development, with infants actively constructing their own knowledge from both their experiences and biological endowments. Vygotsky and Bronfenbrenner expanded on Piaget's ideas by focusing on the role of culture in children's early experiences, while Erickson and Bowlby described infants' attachment to their mothers as the foundation of the infant's relationships throughout life. A more recent attempt to bridge the nature–nurture debate centers on Core Knowledge, where infants are born with special-purpose knowledge systems, including number, physics, biology, psychology, and language (e.g., Spelke and Kinzler 2007). This view is considered middle ground because it endows infants with only general foundations that require experiences in the world for complete development.

Most current developmental theories reject the nature–nurture dichotomy entirely because advances in embryology and neuroscience indicate that there is no way to separate nature from nurture (e.g., Spencer et al. 2009). Genes code for proteins, which operate in a cellular environment, and that environment changes the expression of genes and the genetic code itself. Experiences affect the developing infant long before birth, affecting molecular interactions, as well as embryonic and fetal development and behavior, making it impossible to draw a distinct line between when nature stops and nurture begins. Moreover, experiences long after birth can alter genetic transcription, again blurring the line. But if new behaviors are not entirely coded in the genes or constructed solely from experience, how do infants learn new behaviors?

Developmental scientists are now exploring the field of infant development from a dynamic systems perspective (e.g., Thelen and Smith 1994). This view offers five principles from which to investigate how infants develop:

1. Development occurs in processes that exist across all levels of an organism, ranging from genetics and the cellular level up through an individual's behavior, embedded within a social and historical context.
2. These levels are constantly interacting, and each interaction can initiate cascading effects across all the other levels.
3. These interactions are self-organizing. There is no level with dominion or control over the others. Instead, infant development, from brains to bodies, involves cascading developmental processes in which genes and their products interact within their local environment to create the substrates for further development.
4. These processes operate over multiple time scales. Infants' moment-to-moment experiences lay the foundation for changes that occur over weeks, months, and years. These processes also operate over longer time scales, resulting in cultural and biological evolution. In order to understand development, one must consider all the different interacting time scales.
5. New behaviors arise over time from small changes in one system that have cascading effects across all the developing systems. During periods of stability, all the elements of the system work together smoothly. Instability can arise from a small change in any one system (e.g., learning to reach or early joint attention). During periods of instability, the system is open to multiple flexible solutions and the emergence of new behaviors. As new solutions are tried, those that are successful are repeated, and learning occurs as the system adapts to the instability and settles back into stability.

One key consequence of this integrated systems view has been the blurring of previously distinct areas of infant development. Historically, researchers have investigated motor development, perceptual development, cognitive development, and socio-emotional development, each as a separate domain. The dynamic systems perspective eliminates these boundaries, instead focusing on the interactions among all of these developing systems within the infant.

Important Scientific Research and Open Questions

By this view, infant cognition is embodied, such that every decision to act is assembled in the moment, with contributions from memory, attention, and action. These decisions are informed by what infants have just done, their motor skill level, the perceptual layout of the environment, who is near them, and the salience of the task. This shift to view infant learning and cognition as embodied has generated a reexamination of infant habituation tasks, which comprise the backbone of the field of infant perception and cognition. In habituation tasks, infants are shown a display or an event repeatedly until looking time decreases. Then, they are shown a slightly different "test" display or event. If looking time increases, researchers conclude that infants discriminated the two events and that this increased looking reflects infants' knowledge or understanding of some concept. But during this task, infants attend to the display, visually process it, and look away from it, with these behaviors occurring repeatedly throughout the task. By focusing on the multiple causes that produce these behaviors, and how the history of the system might influence whether or not and for how long infants look at the test displays, we know now that multiple factors influence infants' decisions to look at a stimulus: the history of looks across trials, the salience of the displays, the number and order of habituation and test trials, and the complexity of the displays (Schöner and Thelen 2006). Thus, current questions in this area now focus on why infants attend to some displays and not others, and how infants make decisions to look and look away.

Another key question in infant cognition is the impact of rapidly changing motor skills on cognitive development. What an infant learns across a range of topics, including spatial relations, reaching for objects, navigating around obstacles, or judging the safety of a surface for traversal, depends on how that infant moves through the world, where she has gone before, and what she attends to. For example, numerous studies have reported that small changes in posture or the feel of the body can alter what infants appear to know about the location of hidden objects or spatial relations. These studies raise serious questions of what it means for infants to know something. Indeed, they suggest that infants do not just learn disembodied abstract "concepts"; the feel of the body during learning is linked to what is learned (Thelen and Smith 2006). Current research is now exploring the link between infants' understanding of concepts and the movements needed to express those concepts.

Similar questions have been raised about infants' early socio-emotional development. Infants' interactions with their caregivers are critical in their development of internal working models that guide their feelings, thoughts, and expectations in later relationships. These interactions have now been linked to locomotor advances, where the onset of crawling and walking impacts infants' emotional expression, attachment, social referencing, and initiations of social interactions (e.g., Campos et al. 2000). Open questions in infant social development focus on the interactions among temperament, attachment style, and culture as they relate to developing motor and cognitive capabilities.

Throughout infancy, processes such as perception, action, attention, memory, cognition, and social behaviors all shift to accommodate infants' experiences in the world, and each process affects and is affected by the changes in the other processes. Those experiences are what make development, what inspire change, and create new modes of thinking and acting.

Cross-References

► Affordances
► Approximate Learning of Dynamic Models/Systems
► Development and Learning (Overview)
► Habituation in Infant Cognition
► Learning Action Affordances and Action Schemas

References

Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel broadens the mind. *Infancy, 1*(2), 149–219, 397.

Schöner, G., & Thelen, E. (2006). Using dynamic field theory to rethink infant habituation. *Psychology Review, 113*, 273–299.

Spelke, E. S., & Kinzler, K. D. (2007). Core knowledge. *Developmental Science, 10*, 89–96.

Spencer, J. P., Thomas, M. S. C., & McClelland, J. L. (2009). *Toward a unified theory of development*. New York: Oxford University Press.

Thelen, E., & Smith, L. B. (1994). *A dynamical systems approach to the development of cognition and action*. Cambridge, MA: Bradford Books/MIT Press.

Thelen, E., & Smith, L. B. (2006). Dynamic systems theories. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology: Vol. 1: Theoretical models of human development* (6th ed., pp. 258–312).

Infant Learning and Memory

Rachel Barr[1], Carolyn Rovee-Collier[2]
[1]Department of Psychology, Georgetown University, Washington, DC, USA
[2]Department of Psychology, Rutgers University, Piscataway, NJ, USA

Synonyms

Association; Cognition; Encoding; Representation; Retention

Definition

Learning and memory are intimately linked; tests of learning are, in fact, tests of memory. *Learning* is defined as a relatively permanent change in behavior that results from experience. This definition excludes temporary behavioral changes due to arousal, fatigue, illness, medication, or biological rhythms as well as more permanent changes associated with aging, growth, or physiological intervention. *Memory* is the product of a series of processes that include the encoding, storage, and retrieval of the representation of an experience. For learning to occur, the representations of two discrete events must be associated, which occurs when they are simultaneously active in short-term memory (memory *in* learning, associative memory). As long as the memory of the association remains active, it is vulnerable to modification, but once it enters long-term memory (an inactive state), it is relatively permanent. The memory of prior learning can be retrieved (returned to an active state), updated, and either returned to an inactive state or behaviorally expressed on a test (memory *of* learning, retentive memory). The fundamental processes of learning and memory do not change developmentally, but the temporal parameters and contents of memories do.

Theoretical Background

Human infancy extends from birth through 2 years of age. During this period, infants undergo major physical and behavioral transformation, and few vestiges of the newborn are evident when the infancy period ends. Since Freud first concluded that adult behavior could be traced to infantile experiences, the long-term effects of early experience have evoked considerable theoretical interest. Most developmental scientists have assumed that infants' experiences progressively build on one another and are foundational for later cognitive development. Implicit in this assumption is a capacity for long-term memory. If early experiences have an enduring impact on later behavior and cognition, then infants must possess some means of preserving a relatively enduring record of those experiences. Paradoxically, most scientists have also believed that preverbal infants are incapable of remembering their experiences over the long term. The phenomenon of infantile amnesia – the common experience that adults cannot remember events that occurred before 3–4 years of age – lent credence to this belief. This paradox still drives modern research and theory on infant learning and memory (Rovee-Collier et al. 2001).

Important Scientific Research and Open Questions

Infant Learning

The categories of learning that most authorities distinguish, ordered from simplest to most complex, are habituation, classical conditioning, instrumental and operant conditioning, various types of complex learning (conditional discrimination, serial-order learning, categorization, detour learning, context learning), concept learning (oddity concept, same-different concept), imitation, and language acquisition. These categories form a phylogenetic continuum, with the most primitive organisms anchoring one end and the most complex organisms (humans) anchoring the other. For many decades, the ontogeny of learning was thought to recapitulate its phylogeny. Today, learning in all categories has been documented within days of birth.

Initial investigations of infant learning were undertaken to document the origins of adult behavior. Using procedures designed for adults, they provided a disappointing view of infant learning. Pavlov, for example, attributed failed classical conditioning attempts with young infants to cortical immaturity. Decades later, researchers found that increasing adults' optimal interstimulus interval by two to three times produced rapid classical eyelid conditioning in 10-day-olds and even sleeping newborns. (Sleeping adults cannot learn new associations.) Using procedures designed for infants, researchers found that newborns rapidly acquire conditioned feeding reflexes. During a scheduled feeding period, for example, they paired a tone with tactile stimulation to the right cheek, which elicited a right headturn that led to the delivery of milk from the right side. Similarly, they paired a buzzer with stimulation to the left cheek, which elicited a left headturn that led to milk delivery from the left side. Newborns learned to turn right when the tone sounded and left when the buzzer sounded (Rovee-Collier et al. 2001). In another example, infants exhibited a preference for a chamomile odor that had been associated with breastfeeding during their first 8 days of nursing. At 7 months of age, infants presented with differently scented teething rings preferred the chamomile-scented one; at 21 months, they chose to play with a chamomile-scented toy.

The neural mechanisms that support newborn learning become functionally mature during the prenatal period, before they would normally be exercised. The characteristics of the mother's voice, for example, are learned prenatally. After birth, infants orient and root in the direction of the mother's voice, increasing the efficiency of breastfeeding regardless of whether they are being held on her left or right. Also, newborns whose mother had read aloud a Dr. Seuss passage daily during the last 6 weeks of gestation rapidly learned to suck on a nonnutritive nipple to activate a tape-recording of their mother (but not another woman) reading the same passage. Moreover, infants sucked harder to listen to her read the same passage than another one. Similar prenatal learning familiarizes organisms with the linguistic environment into which they will be born.

Beginning in mid-1980, thinking was dominated by the assumption that infants cannot learn a given behavior until the neural circuit that underlies that learning in adults becomes functionally mature. Most scientists believed that a primitive memory system limits infant learning to simple procedures and perceptual-motor skills until 10 months of age, when the brain mechanisms that support adult learning develop. Afterwards, infants can form relational and contextual memories and memories of specific episodes and cognitive associations. More recently, researchers found that infants exhibit adult-like learning long before the brain structures that mediate similar adult learning develop. This evidence indicates that younger infants possess alternate learning circuits (Rovee-Collier and Giles 2010). *What those circuits might be remains to be determined for each modality.* At 3 and 6 months of age, for example, infants learn serial lists, form contextual, functional, and ad-hoc categories of arbitrary stimuli, spontaneously detect correlated attributes, and, at 6 months, use correlated attributes to categorize. They also learn incidental contextual information, form spontaneous cue-context associations, exhibit context-dependent renewal, and spontaneously associate two objects that merely appear together in their visual surround. After watching an adult model a sequence of actions on one of the paired objects, 6-month-olds imitated them on the other object 1 day later; 3-month-olds, who were periodically reminded until they could perform the actions, imitated them on the other object 3 months later.

Six-month-olds remembered the same modeled actions 6 weeks after associating them with the retrieved memory of an operant task that was remembered for 8 weeks. They formed a bidirectional, linear chain of associations that were linked over days by overlapping members and exhibited transitivity of equivalence relations between remote members of the five-object chain. Finally, they indirectly associated the simultaneously activated memory representations of two stimuli in their physical absence (Rovee-Collier and Cuevas 2009). Infants demonstrated the preceding adult-like behavior on transfer tests of *simultaneous* associations – associations that infants younger than 10 months can form rapidly and effortlessly, but 12- and 15-month-olds cannot. Conversely, older infants can form sequential associations, but 3- and 6-month-olds cannot. At 18 months, infants form both. Infants can also learn information from books, television, and touch screens and transfer that learning to real world objects. Although 12- to 24-month-olds learn significantly less from 2D models than from 3D models, termed the *media deficit* effect, 6-month-olds learn from both equivalently (Barr 2010).

By the time infants locomote independently (8–9 months), they have already learned what happens in what places. Afterward, they learn the spatial relationships between these places (a *cognitive map*), facilitating navigation between places. From 12 to 18 months, infants learn to locate objects using landmarks; from 18 to 24 months, they learn to reorient using geometric cues in the environment.

Infant Memory

Early information about infant memory came from paired-comparison studies of looking patterns. This paradigm exploits the tendency of infants older than 8 weeks to look proportionally longer at a new stimulus than at an old one (Rose et al. 2004). After exposure to one stimulus, a delay is introduced before infants are tested simultaneously with the exposed stimulus and a new one. Recognition of the old stimulus is inferred from a significant novelty preference, and its maximum duration is the longest delay at which infants exhibit a novelty preference. Although the duration of novelty preferences increases throughout the first postnatal year (e.g., 4 months: 0–10 s; 9 months: 75–150 s), it never exceeds seconds to minutes. This duration is within the range of short-term memory (STM) in children and adults, the ISI in classical conditioning, and the delay of reinforcement in operant conditioning. This correspondence suggests that the duration of novelty preferences is a measure of associative memory, or memory in learning.

Current knowledge of long-term memory (LTM) between 2 and 24 months of age has come from operant conditioning and deferred imitation research. In both paradigms, infants of all ages have equivalent retention after short test delays, but older infants remember longer as the test delay increases. Using age-calibrated parameters, researchers found that operant retention increases linearly from 1 to 2 days at 2 months of age to 13–14 weeks at 18 months; retention of the modeling event also increases linearly from 1 day at 6 months to 4 weeks at 18 months (Rovee-Collier and Barr 2010). Although the absolute magnitude of retention in the two paradigms differs, the pattern of retention in both is the same. The duration of retention is not fixed but is altered by changing the parameters of training. The magnitude of these effects is not limited by the immaturity of the infant brain. In fact, the effects are greater at younger ages, when retention is shorter. Increasing the number of sessions from two 9-min sessions to three 6-min sessions, for example, increases operant retention at 2 months from 1–2 days to 2 weeks; increasing modeling duration from 30 s to 60 s increases deferred imitation at 6 months from 0–1 s to 24 h. At all ages, retention is prolonged by increasing session duration, session number, number of retrievals, session spacing, retrieval difficulty, repetitions, the distinctiveness of the training context, stimulus complexity, number of associations, and selective attention to the target. Associating a new learning problem with a retrieval cue for a strong prior association facilitates encoding; maximizing the similarity between the encoding and test contexts facilitates retrieval.

Regardless of paradigm, the basic memory process is the same in infants and adults: Memories are forgotten gradually, reactivated by a reminder, and modified by new information that overlaps with old. The temporal parameters of memory processing change with age, but these changes are not maturational. Three-month-olds, after more retrieval experiences, exhibit the behavioral characteristics of 12-month-olds. *The neuroscience of repeated retrieval experiences is unknown.* Members of new associations can be linked to members of other associations in a complex mnemonic network, the links are strengthened each time a member in the network is activated (retrieved), and the activation spreads through the network. This process is likely to be the mechanism by which the early knowledge base is formed and expanded.

The learning and memory deficits that distinguish atypically from typically developing children are likely to make their first appearance in transfer tasks administered to young infants. The earlier deficits are detected, the sooner interventions can be introduced that could potentially minimize or even alleviate the problem. *This important line of inquiry has yet to be pursued.*

Infantile Amnesia

Early accounts attributed infantile amnesia to infants' inability to form mental representations, enduring memories of events, or rehearse prior experiences by talking about them. The most satisfying recent account resulted from findings that infants could not verbally recall an event that occurred before they possessed words to describe it. Even though the words were in their vocabulary when they were tested, they did not use them. On a nonverbal test with perceptual cues, however, their recognition was excellent. Researchers concluded that (1) memory performance is specific to the conditions of encoding, not testing, and (2) memories encoded in a perceptual format cannot be retrieved by cues from a different format. *These findings leave open the question of the long-term effects of early experience. This question might be addressed if an event memory that was encoded in a perceptual format were used in a transfer task to facilitate new learning (including verbal learning) or solve a novel problem. This question is related to another open question regarding how different learning mechanisms interact with one another.*

Cross-References

► Ecology of Learning
► Encoding Specificity and Variability: Effects on Learning
► Habituation in Infant Cognition
► Habituation in Infant Learning
► Infant Learning and Development
► Memory Consolidation and Reconsolidation
► Rapid Learning in Infants
► Reactivation and Consolidation of Learning During Sleep
► Reinstatement of Learning
► Zone of Proximal Development

References

Barr, R. (2010). Transfer of learning between 2D and 3D sources during infancy: Informing theory and practice. *Developmental Review, 30*, 128–154. doi:10.1016/j.dr.2010.03.001.

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2004). Infant visual recognition memory. *Developmental Review, 24*, 74–100.

Rovee-Collier, C., & Cuevas, K. (2009). Multiple memory systems are unnecessary to account for infant memory development: An ecological model. *Developmental Psychology, 45*, 160–174.
Rovee-Collier, C., & Giles, A. (2010). Why a neuromaturational model of memory fails: Exuberant learning in early infancy. *Behavioural Processes, 83*, 197–206.
Rovee-Collier, C., Hayne, H., & Colombo, M. (2001). *The development of implicit and explicit memory.* Amsterdam: John Benjamins.
Rovee-Collier, C., & Barr, R. (2010). Infant memory. In J. G. Bremner & T. D. Wachs (Eds.), *Wiley-Blackwell handbook of infant development. Vol. 1: Basic research* (pp. 271–294). Wiley-Blackwell: Chichester.

Inference to the Best Explanation

► Abductive Learning
► Abductive Reasoning

Inferential Learning and Reasoning

Norbert M. Seel
Department of Education, University of Freiburg, Freiburg, Germany

Synonyms

Content-extending reasoning; Illative faculty of the mind; Interpretation-based learning

Definition

In contrast to ► acquisitive learning and ► experiential learning, i*nferential learning* refers to a kind of learning which enables people to construct new knowledge by thinking. The knowledge produced in this manner does not necessarily need to have any connection to experiences, although it originates in them. The thinking operations involved in this process of knowledge construction are inferential and content extending. However, this requires from the learner a conviction that there are regularities in the world which, although they might escape immediate observation, can be inferred by logical reasoning. Inferential learning includes (a) deductive reasoning (as truth conserving thinking), (b) inductive reasoning (as content-extending thinking) aiming at ► predictive inferences, and (c) abductive reasoning.

Theoretical Background

Humans are capable of adapting to changes in their surroundings promptly and sensitively. They do this either through *habituation*, i.e., by modifying their behavioral patterns to fit their surroundings, or through *cognitive learning*. The term "cognitive learning" refers to higher and conscious levels of information processing which bring about changes in knowledge and skills as well as improvements in the ability to solve problems. Basically, cognitive learning means that something that was not previously known becomes idiosyncratic knowledge. It is associated with the internalization of something outside of a person that existed prior to its comprehension. However, humans can also produce new knowledge without referring to experiences just by thinking, i.e., by operating with knowledge which aims at producing new knowledge. Actually, it is possible to produce new knowledge by executing thinking operations that can be of a concrete or a formal nature. The knowledge created by means of reasoning and reflective thinking does not necessarily need to have any connection to experiences, although it always originates in them.

As a whole, the phenomenon of inferential thinking includes deductive reasoning (as truth conserving thinking) and inductive reasoning (as content-extending thinking). Additionally, Peirce (1878) introduced a third form of inference: *abduction.*

Since ancient philosophy, *deductive reasoning* has been the central domain of formal logic. It is the art of deducing true conclusions logically from true premises and studies how the validity of inferences and argumentations are dependent on their logical (and linguistic) form. Although deductive reasoning has been considered the quintessence of formal logic since ancient times, it has been challenged by prominent philosophers such as Schopenhauer (1818), who argued that deductive reasoning in everyday life is not done in accordance with the rules of logic but rather that logic "is nothing more than the knowledge in the abstract of what every one knows in the concrete . . . To desire to make practical use of logic means, therefore, to desire to derive with unspeakable trouble, from general rules, that which is immediately known with the greatest certainty in the particular case" (Schopenhauer 1818, *The World as Will and Representation*, I, § 9; translated by Haldane and Kemp 1948).

In contrast to formal logic, psychology of thinking is interested primarily in the psychological status of logical inferences inasmuch as they are related to thinking processes. Concisely, psychology of thinking deals with the psychological laws of *how (and why) people hold something to being true*. Consequently, cognitive psychologists (such as Johnson-Laird 1983) argue that humans are capable of making deductive inferences of a certain degree of complexity without having knowledge of or applying the rules for logical reasoning. Rather, most people make inferences on the basis of mental models or pragmatic reasoning schemas.

This also holds true with regard to *inductive reasoning*. One of the most remarkable characteristics of human learning and thinking is the ability to produce generalizations on the basis of individual experiences and to create, for instance, semantic classes. Inductive reasoning plays an important role in this process. Induction may be defined broadly as the development of general rules, ideas, and concepts from individual examples. Inductive reasoning has long played a central role in psychology – especially in research on human intelligence, where authors since Thurstone have viewed the ability to make inductive inferences as a central characteristic of intelligent behavior (Holyoak 1984).

Induction enables people, on the basis of only a few examples, to reach a conclusion that makes it possible to make predictions for new examples. However, there is no certainty that a general conclusion reached through inductive reasoning will be correct. A main focus of psychological interest in inductive reasoning is the study of how people solve analogous problems: "Analogy is an especially effective inductive mechanism . . . which decides on every plausible idea about everything or nothing" (Holland et al. 1986, p. 312). When people draw a ► conclusion by analogy, they are using an inductive process to gain new knowledge about attributes of a particular phenomenon on the basis of their knowledge of its similarity to another phenomenon. As with deductive reasoning, the most important theories in cognitive psychology which attempt to explain the process of analogy-based reasoning are the mental model-based structure-mapping approach of Gentner (1983) and schema-theory-based approaches.

Model-based approaches of inductive reasoning operate with the conception of analogy models, which has been exemplified by Holyoak and Thagard (1995) in the following way: General knowledge about water enables individuals to create a mental model of how water moves. In the same way, knowledge about sounds enables them to create a mental model of how sound is transmitted through the air. Each of these mental models links a representation with a phenomenon in the physical world. Now, when individuals create an analogy between waves in the water and the spreading of sound through the air, they build an *isomorphism between two mental models*. They can use the model of water to progressively modify and improve the model of sound. However, in the end they must validate this explanation by testing whether the analogy between the two models has helped them to achieve a better understanding of the phenomenon to be explained. Consequently, conclusion by analogy is not based on a structurally compatible relationship between a mental model and the outside world, but rather on a relationship between two mental models which represent different phenomena of the world. Seel (1991) has interpreted this theoretical conception by referring to the logic of "possible worlds." According to this interpretation, the relation between models can be understood as a relation of accessibility to "possible worlds" in which all possible mental models of analogous phenomena can be mapped and are then correct. Conclusion by analogy is thus founded on a *reduction to absurdity*: It is a process of testing whether there is a "possible world" in which the mental model of the base domain is correct but that of the target domain turns out to be false. In other words, on the basis of available world knowledge one can create any number of mental models of the target domain whose content and structure are to a greater or lesser degree compatible with the model of the base domain. The mental model of the target domain which fits the mental model of the base domain best is included in the solution model on which the conclusion by analogy is based – provided that there is no alternative model of the target domain which fits the model of the base domain at least as well.

In contrast to the view that deduction and inductive generalization are sufficient to account for the creation of new knowledge, it can be argued that knowledge also arises from experience by processes of *abduction*, which is sometimes called the *the logic of Sherlock Holmes* (Josephson and Josephson 1994). Abduction is inference to the best explanation, a pattern of reasoning that occurs, for instance, in medical diagnostics, scientific theory formulation, or accident investigation. The idea of abduction goes back to Peirce and refers to the selection and the formation of plausible hypotheses. Basically, abductive reasoning has the logical form of an inverse *modus ponens* and is “reasoning backward” from consequent to antecedent. This can be illustrated by a comparison of the basic forms of deduction, induction, and abduction as shown in Table 1.

Peirce has also called abductive reasoning *retroductive reasoning*. From a logical point of view, reasoning backwards is not a valid form of logical inference but is a form of conjectural or presumptive thinking which aims at matching pragmatic standards of plausibility. Accordingly, the term “abductive learning” denotes a particular type of learning which occurs when reasoning over a model fails to produce the expected results. This kind of learning is a way of generating new ideas. A learning mechanism is proposed on how to select hypotheses from a set of possible hypotheses based on abductive reasoning. Abductive reasoning is concerned with inferring an explanation of why observations could have occurred. In abduction, this explanation is called a hypothesis which is selected from a set of given possible hypotheses. Abduction looks for a pattern in a phenomenon, but then it goes on to first suggest and then test a hypothesis or theory. It is in the area of hypothesis generation that people sometimes show great creativity in formulating astonishingly insightful naïve theories based on only a few observations. It seems quite likely that this type of learning is based on reasoning by analogy and other mechanisms for exploiting a person’s mental models. Abduction is very similar to reasoning by analogy, and in fact hypothesis generation through abduction seems particularly associative or analogous in nature. An interesting approach to explaining abductive reasoning is the idea of *probabilistic mental models* introduced by Gigerenzer et al. (1991). This type of mental model is not the product of long contemplation, but rather of the spontaneous creation of plausibility. It goes beyond the existing structure of a problem and is based on the judgment of the plausibility of the “truth” of a proposition.

Important Scientific Research and Open Questions

The various kinds of inferential reasoning have formed the core of philosophy since ancient times and are still at the heart of formal logic and semantics today. Due to the origins of inferential reasoning in philosophy, psychologists investigating human thinking have traditionally also been concerned with logical reasoning and productive thinking, as may be seen in the works of Duncker, Külpe, Selz, and others. Inferential learning and reasoning also plays a central role in the seminal work of Piaget, for whom deductive reasoning is closely associated with formal thinking and the “destination” of intellectual development. In accordance with this tradition, most textbooks on cognitive psychology (e.g., Anderson 2009) focus more or less extensively on deductive and inductive reasoning within the broader scope of problem solving by people with no previous training in formal logic. The literature on

Inferential Learning and Reasoning. Table 1 Basic forms of reasoning as given by Kugel (1986)

	Deduction	Induction	Abduction
Given premise	All men are mortal	Socrates is a man	All men are mortal
	(*Rule*)	(*Case*)	(*Rule*)
Given premise	Socrates is a man	Socrates is mortal	Socrates is mortal
	(*Case*)	(*Result*)	(*Result*)
Conclusion	Socrates is mortal	All men are mortal	Socrates is a man
	(*Result*)	(*Rule*)	(*Case*)

this topic often takes it for granted that deductive reasoning is related by definition to the conception of logic, in which syllogistic problems are seen as prototypes of deductive reasoning. As a consequence, psychologists often lack comprehensive theoretical models to describe deductive and inductive reasoning. This deficiency has practical consequences since available approaches for the psychological study of deductive and inductive reasoning do not provide a sufficient basis for educational training for this form of thinking. On the other hand, it has been shown that people seldom solve syllogisms and logical problems using the rules of formal logic. Rather, they typically fall back on their own experiences and views and tolerate logical fallacies. This has been well documented for decades, as is illustrated by the research of Woodworth and Sells (1935) on the effects of *atmosphere* in ► syllogistic reasoning.

In the 1980s, cognitive psychologists referred to earlier psychological studies on syllogistic reasoning and developed new theoretical approaches to deductive reasoning. These approaches can be divided into two main classes: (a) *syntactic approaches*, which assume that people apply syntactic rules of a "mental logic" when practicing deductive reasoning (Rips 1984); and (b) *semantic or pragmatic approaches*, which are based on the use of judgment schemas or mental models (Cheng and Holyoak 1985; Johnson-Laird 1983) which enable "mental leaps" in the establishment of truth values and operate only under the premises which are directly consistent with the conclusion. Thus, mental models make it possible for people with minimal information to reach correct conclusions since they test the truth value of only the premises which are subjectively plausible and do not contradict the conclusion when combined with one another.

Examples from research demonstrate the great flexibility of the theory of mental models. In fact, Bonatti (1994) considers this theory so flexible that it is – ironically stated – consistent with almost anything one wishes to research: making correct and incorrect inferences in deductive reasoning, dealing with propositions which are ambiguous or unambiguous, etc. However, in many cases, the theory of mental models leads to false predictions and has therefore been contrasted to the theory of mental logic, which argues that inferences are made on the basis of formal rules of deduction (Braine 1990).

Research over the past decades demonstrates that people can perform deductive reasoning either by applying the rules of a system of mental logic or by applying a mental model and going through the various means of interpreting the premises of a proposition. Despite this, cognitive scientists do not agree on how much of deductive reasoning is performed through rational processes and to what extent it is influenced by pragmatic aspects that could lead to systematic, nonlogical distortions. All in all, it must be stated that deductive reasoning has not yet been studied sufficiently from a psychological point of view, as is reflected by the fact that it is still unclear which cognitive operations are involved in deductive thinking.

This statement also holds true with regard to inductive reasoning, although there is a huge body of research that considers induction to be a central component of intelligence. As with the area of deductive reasoning, recent approaches to inductive reasoning in cognitive psychology emphasize the application of either schemas or mental models. Actually, for more than 30 years numerous studies have demonstrated that learners develop an inferential schema when processing several analogous phenomena at the same time, and that they then use a similar structure when processing new phenomena. The construction of an inferential schema on the basis of multiple analogues is obviously a procedure which is not only lengthy but is also prone to error (Alexander et al. 1997; Antonietti 2001). Although learners are capable by a certain age of making analogies spontaneously and using them to solve problems, they can do so only if they do not allow themselves to be deluded by the superficial attributes of analogous phenomena. Rather, they must push forward to the structural similarity relevant for solving the analogy. When adequate inferential schemas have been developed, they can be applied immediately and routinely to new situations and phenomena. In fact, schema-theoretical approaches can even be said to presuppose a program of direct, routine inductive reasoning.

However, as with deductive reasoning some authors emphasize the special function of mental models for conclusion by analogy as a means of inductive reasoning when inferential schemas are not available or applicable (Johnson-Laird 1983; Seel 1991). However, until now, very little research has been conducted on the function of mental models for inductive and analogical reasoning. Probably, this will be a promising area of research for the future.

A different picture can be drawn with regard to research on the effectiveness of training in inductive reasoning. It has been demonstrated that inductive and analogical reasoning can be trained systematically and successfully (see, for instance, Alexander et al. 1987; Klauer and Phye 2008). This research is especially relevant for instructional purposes.

Compared with research on deductive and inductive reasoning, the area of abductive reasoning is still in its infancy. As an approach for finding the best explanation, abductive reasoning has been introduced and discussed especially in the fields of artificial intelligence and expert systems. Expert systems aim at imitating the reasoning process and the human faculty to deal with uncertain information in an efficient way. According to Josephson and Josephson (1994) the critical question is how a pragmatic strategy of reasoning like abductive inference can be implemented in expert systems and whether a computational automaton-like artificial intelligence can make creative guesses. Beyond its application within the realm of artificial intelligence and expert systems, abductive reasoning has also been investigated in cognitive psychology. For instance, Krems (1995) examined qualitative and quantitative aspects of complex problem solving in several domains of abductive reasoning: medical diagnostics, automobile repair, and computer program debugging. Using a line of argumentation reminiscent of the approach of case-based learning and abductive reasoning, Krems contended that flexibility in problem solving requires the solver to acquire relevant knowledge and new skills very quickly in unfamiliar situations and to apply and adapt previous knowledge to meet the demands of the new situation. Flexibility refers in this case to the choice and/or change of available techniques, methods, or strategies of problem solving to meet the demands of a task or situation. Interestingly, the experiments carried out by Krems indicated that it is necessary to apply different strategies of abductive reasoning for different fields of interest. For example, a "breadth first strategy" was most often used to correct computer programming errors, whereas a "depth first strategy" was more often used for diagnosing malfunctions in the automobile repair shop. As in the case of inductive reasoning, the area of abductive reasoning lacks substantial research in comparison with the field of deductive reasoning.

Cross-References

▶ Abductive Learning
▶ Abductive Reasoning
▶ Analogical Model(s)
▶ Analogy-Based Learning
▶ Deductive Reasoning and Learning
▶ Default Reasoning
▶ Experiential Learning
▶ Inductive Reasoning and Learning
▶ Learning and Thinking
▶ Model Based Reasoning
▶ Pragmatic Reasoning Schemas
▶ Schema-Based Reasoning

References

Alexander, P. A., White, C. S., Haensly, P. A., & Grimmins-Jeanes, M. (1987). Training in analogical reasoning. *American Educational Research Journal, 24*, 387–404.

Alexander, P. A., White, C. S., & Daugherty, M. (1997). Analogical reasoning and early mathematics learning. In L. D. English (Ed.), *Mathematical reasoning: Analogies, metaphers, and images* (pp. 117–147). Mahwah: Lawrence Erlbaum.

Anderson, J. R. (2009). *Cognitive psychology and its implications* (7th ed.). New York: Worth Publishers.

Antonietti, A. (2001). *Analogical discoveries. Identifying similarities to solve problems.* Roma: Carocci.

Bonatti, L. (1994). Propositional reasoning by model? *Psychological Review, 101*(4), 725–733.

Braine, M. D. (1990). The natural logic approach to reasoning. In W. Overton (Ed.), *Reasoning, necessity and logic: Developmental perspectives* (pp. 133–157). Hillsdale: Erlbaum.

Cheng, P. W., & Holyoak, K. J. (1985). Pragmatic reasoning schemas. *Cognitive Psychology, 17*, 391–426.

Gentner, D. (1983). Structure mapping: A theoretical framework for analogy. *Cognitive Science, 7*, 155–170.

Gigerenzer, G., Hoffrage, U., & Kleinbölting, H. (1991). Probabilistic mental models: A Brunswikian theory of confidence. *Psychological Review, 98*(4), 506–528.

Holland, J., Holyoak, K., Nisbett, R., & Thagard, P. (1986). *Induction: Processes of inference, learning, and discovery.* Cambridge: MIT Press.

Holyoak, K. J. (1984). Analogical thinking and human intelligence. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 2, pp. 199–230). Hillsdale: Erlbaum.

Holyoak, K. J., & Thagard, P. (1995). *Mental leaps. Analogy in creative thought.* Cambridge: MIT Press.

Johnson-Laird, P. N. (1983). *Mental models. Towards a cognitive science of language, inference, and consciousness.* Cambridge: Cambridge University Press.

Josephson, J. R., & Josephson, S. G. (Eds.). (1994). *Abductive inference. Computation, philosophy, technology.* New York: Cambridge University Press.

Klauer, K. J., & Phye, G. D. (2008). Inductive reasoning: A training approach. *Review of Educational Research, 78*(1), 85–123.

Krems, J. F. (1995). Cognitive flexibility and complex problem solving. In P. A. Frensch & J. Funke (Eds.), *Complex problem solving. The European perspective* (pp. 201–218). Hillsdale: Lawrence Erlbaum.

Kugel, P. (1986). Thinking may be more than computing. *Cognition, 22*, 137–198.

Lorenz, K. (1980). Sprachphilosophie. In H. P. Althaus, H. Henne, & H. E. Wiegand (Eds.), *Lexikon der germanistischen Linguistik* (pp. 1–28). Tübingen: Niemeyer.

Peirce, C. (1878). How to make our ideas clear. *Popular Science Monthly, 12*, 286–302.

Rips, L. J. (1984). Reasoning as a central ability. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 2, pp. 105–147). Hillsdale: Erlbaum.

Schopenhauer, A. (1818). *The World as Will and Idea.* The second German edition. (1948). (Trans: Haldane, R. B. and Kemp, J.). London: Routledge & Kegan Paul.

Seel, N. M. (1991). *Weltwissen und mentale Modelle.* Göttingen: Hogrefe (World knowledge and mental models).

Woodworth, R. S., & Sells, S. B. (1935). An atmosphere effect in formal syllogistic reasoning. *Journal of Experimental Psychology, 18*, 451–460.

Further Reading

Heidegger, M. (1968). *What is called thinking?* New York: Harper & Row.

Inferential Learning Theory

► Inferential Theory of Learning

Inferential Strategies

► Multistrategy Learning

Inferential Theory of Learning

Kenneth A. Kaufman
Machine Learning and Inference Laboratory, George Mason University, Fairfax, VA, USA

Synonyms

Inferential learning theory

Definition

The Inferential Theory of Learning (ITL) is a means of classifying and understanding learning processes, both cognitive and machine, by the types of inference they make and by the way knowledge is created and transformed through learning. Such a view of learning processes is in contrast to the Computational Theory of Learning, in which learning strategies are organized by their computational complexity. Through the Inferential Theory, a learning process can be described as one or more knowledge transmutations (e.g., induction, abstraction, similization).

Theoretical Background

The Inferential Theory of Learning (ITL) was proposed by Michalski (1991, 1994) as a unified framework for developing and implementing multistrategy learning systems. ITL recognizes a learning process as consisting of three components: the input facts, the background knowledge, and the inference strategy being employed to generate new knowledge and thereby enhance the background knowledge for future tasks.

A learning task employs one or more knowledge transmutations, depending on the learning goal and the relationship between the generated knowledge and the prior knowledge. The knowledge transmutations defined in ITL include the following pairs of opposite operators:

- Generalization/Specialization, in which the reference set of a statement is expanded/contracted. For instance, going from "all beagles are mammals" to "all dogs are mammals" would be a generalization, while inferring in the reverse direction would be a specialization.
- Concretion/Abstraction, in which descriptive information is added to/removed from the reference set. For instance, the statement "all my pets are beagles" can be abstracted into "all my pets are dogs"; the contents of the reference set (my pets) has not changed, but rather the level of detail in the descriptor.
- Selection/Generation, in which a set of entities is contracted or expanded according to some criterion. Selecting the most representative examples of a concept is an example of the former transmutation, while hypothesizing new cases that would conform to a rule is an example of the latter.

- Similization/Dissimilization, in which a new description is created based on an entity's similarity or lack thereof to a known entity. For instance, the sports of field hockey and lacrosse both have similar fields, fairly small balls, goals, and devices used to move the ball. Knowing that the general objective of field hockey involves a team passing and moving the ball with their sticks in order to get it into a defended goal, one might infer that the rules of the two sports have much in common, and thus lacrosse may utilize the same objective. However, given that tennis has a smaller playing area, often without a grass surface, and a net stretching across the middle, we would expect its objective to be very different in nature from those of either of the other two.
- Reformulation/Randomization, in which a new description differs from the one from which it was derived. In reformulation, the new description should be equivalent, as in translating a sentence from English to French. In randomization, the change is random, rather than directed, and brings about a different meaning in the resulting description. For instance, a randomization might replace the first noun in a sentence with a randomly chosen noun from the dictionary.
- Replication/Removal, in which knowledge structures are copied or deleted, respectively. Memorizing verbatim a written work is a replication operation, and forgetting it the next day is a removal.

Learning tasks can also be classified by the types of inference performed, be they synthetic, analytic, or analogical. Synthetic reasoning generates new knowledge, and is inductive by nature. Analytic reasoning transforms existing knowledge into a more useful form, and thus involves deductive reasoning. Analogical reasoning combines analytic (identifying similarities and correspondences) and synthetic (inducing characteristics of an entity based on the observed similarities) inference. Synthetic methods may be either example guided or by observation, and analytic methods may be guided either by examples or by general specifications. Both synthetic and analytic learning may or may not be constructive, that is, they may or may not involve changing the representation through which knowledge is expressed.

The Inferential Theory is a natural basis for the design of multistrategy learning systems. A control system armed with the knowledge of which tasks are appropriate for which tools can select operators based on the task at hand and provide advice to the user.

Important Scientific Research and Open Questions

Because ITL represents a framework for the development of multistrategy learning systems, the identification and understanding of the uses, capabilities, and limitations of different learning paradigms can be applied to the development of an autonomous or semi-autonomous multistrategy learning system. Representations need to be developed to categorize the learning goal, and a planning system to apply this knowledge would be a necessary component of such a system.

Cross-References

► Analogical Reasoning
► Computational Learning Theory
► Constructive Induction
► Deductive Reasoning and Learning
► Inductive Learning
► Multistrategy Learning

References

Michalski, R. S. (1991). Inferential learning theory as a basis for multistrategy task-adaptive learning. *Proceedings of the First International Workshop on Multistrategy Learning* (pp. 3–18). Harpers Ferry, WV.

Michalski, R. S. (1994). Inferential learning theory: developing foundations for multistrategy learning. In R. S. Michalski & G. Tecuci (Eds.), *Machine learning – A multistrategy approach* (pp. 3–61). San Mateo: Morgan Kaufmann.

Inflections

► Social Interaction Learning Styles

Inflexibility

► Compartmentalization in Learning

Informal Learning

Paul J. Hager
University of Technology, Sydney, Broadway, NSW, Australia

Synonyms

Experiential learning; Incidental learning; Learning from life; Tacit learning; Workplace learning

Definition

Any definition of "informal learning" is circumscribed necessarily by its close connection with the concept of formal learning. As the adjective "informal" suggests, informal learning is usually defined by those particular features that it lacks in relation to formal learning. The concept of formal learning usually includes three necessary features:

1. A specified curriculum
2. Taught by a designated teacher or group of teachers
3. With the learning attainments of individual learners being assessed and certified in some way

These basic requirements can be expanded into a fuller definition as follows:

- Formal learning is that which takes place as intended within formally constituted educational institutions such as schools, colleges, universities, training centers, and so on. Typically it follows a prescribed framework whether or not actual attendance at the institution is necessary. Sometimes there are quite specific outcomes. On other occasions there is more of a kind of broad direction or aim. In all cases however those partaking of courses of formal learning have an idea of what they are likely to learn and they accept that that learning will to some extent be under the control of the institution. (Hager and Halliday 2006, pp. 1–2)

Once formal learning is characterized in this way, informal learning can be defined as all other situations in which people learn. This means, of course, that informal learning encompasses a wide and very diverse range of examples of learning. For instance, learning situations that include only two of the three necessary features for learning to be formal thereby fall into the category of informal learning. One such example would be adult education courses that follow a specified curriculum delivered by designated teachers, but do not include any formal assessment of student learning. Thus educational provision that is sometimes called "nonformal" becomes part of informal learning according to the proposed definition. Likewise, informal learning from life experiences of all kinds represents a very large category within the overall realm of informal learning. For a start there is much informal learning associated with work, especially when work is understood very broadly to include unpaid as well as paid labor. Much informal learning occurs as people prepare to undertake work tasks, as they complete work tasks, and as they extend the range and level of the work tasks that they can perform. The scope of the term "workplace learning" is broader still since it also includes formal vocational learning in workplaces. But informal learning from life experiences extends beyond work to include informal learning through leisure activities such as hobbies, crafts, and sports. It also includes informal learning that assists people to survive in stressful situations, e.g., unemployment, incarceration and dead end jobs.

It may seem unsatisfactory to define informal learning in terms of what it lacks in relation to formal learning. But the bewildering diversity of instances of informal learning suggests that this may be unavoidable. If needs be, specific instances of informal learning can be defined in positive rather than negative terms, e.g., learning from participation in a particular craft. But such craft learning will have features that are specific to itself and that are not shared by all instances of informal learning.

Theoretical Background

Colley et al. (2003) provide the most comprehensive and well-grounded overview and analysis of the informal learning literature that has appeared in recent times. They begin with an informative survey of approaches to characterizing informal learning and distinguishing it from formal learning. They classify these approaches into two main clusters:

- Predominantly theoretical approaches
- Predominantly political approaches

(There is also a small third cluster that combines these two.)

I

They note that informal learning in the workplace is the main focus of the predominantly theoretical approaches. After critically outlining the work of various authors (including Eraut 2000; Billett 2002; Beckett and Hager 2002), they present the following sixfold classification of types of workplace learning devised by Hodkinson and Hodkinson (2004).

This classification is useful for showing the diversity within the workplace learning category. It is notable that while everything in the unintentional/unplanned column falls under informal learning as defined above, the items in the intentional/planned column might be either formal or informal learning depending on whether or not they include the three necessary features of formal learning set out above.

The predominantly political approaches to characterizing formal and informal learning that Colley, Hodkinson & Malcolm discuss encompass two distinct approaches:

- A utilitarian one common in policy documents. This centres mostly on workplace learning conceived more narrowly and instrumentally than it was in the predominantly theoretical approaches.
- An emancipatory political approach based in radical traditions of adult and community education.

Some political approaches seek to distinguish sharply between formal and informal learning for various blunt statistical purposes, e.g., economic development agencies seeking to classify current educational provision in developing countries. However, most of the writers that they consider suggest that there is no hard and fast boundary between formal and informal. Some posit a continuum, e.g., Stern and Sommerlad (1999) propose a ten-step continuum from the formal to the informal.

Different authors react in different ways to the broadly agreed fact that there is no way to distinguish formal from informal learning so that all instances of learning fall on one side or other of the boundary. One approach is to accept that it is a continuum rather than a dichotomy. A more drastic reaction is to deny that there is any distinction here. Colley et al. (2003) take this approach in offering a novel, radical proposal for how the concept of informal learning should be employed. They question the viability of the term "informal learning" except in a very limited range of specific cases. Their arguments for this position are instructive, if less than convincing.

Colley, Hodkinson and Malcolm put forward two main principles to support their position:

1. We should "see attributes of informality and formality as present in all learning situations" (2003, Executive Summary (non-numbered page)).
2. The attributes of informality and formality in all learning situations are claimed to be *interrelated* in crucial ways.

They offer two arguments for the first principle. Firstly, the fact that the literature is unable to reach agreement on how to characterize informal learning. Secondly, they claim to have identified characteristics of both formality and informality in virtually all learning situations that they have encountered. The first argument fails because it does not follow, from the fact that there are seemingly intractable borderline cases, that all cases should be treated as if they are borderline, i.e., as showing features of both formality and informality. The second argument fails because Colley, Hodkinson and Malcolm implausibly attenuate the senses of formal and informal used in their discussion. They use the terms formal and informal in the distinctive senses that these terms have when they are applied to manners, dress, and interpersonal relations. For instance, according to Colley, Hodkinson and Malcolm, if a teacher in a formal educational setting dresses casually, this suffices to render informal the otherwise formal learning situation. Likewise, according to them, if someone learning informally from experience consults a book or even asks an expert for advice, their learning thereby becomes formal as well. The reasoning is that a book is a "formal" document; talking to an expert is a "formal" transaction. However, if formal and informal learning are specifically defined, as they are in this *Encyclopedia* entry, then the Colley, Hodkinson and Malcolm argument fails. According to these definitions, most of the attributes of formality and informality that they discuss have no bearing at all on whether or not learning is informal. This being so, their second principle, which holds that attributes of informality and formality in all learning situations are *interrelated* in crucial ways, becomes dubious. In fact, this claim is merely asserted rather than argued for in any detail, leaving the actual nature of the supposed interaction unclear.

So, as a reaction to the existence of intractable borderline instances when attempting to distinguish formal and informal learning, the Colley, Hodkinson

Informal Learning. Table 1 Types of Workplace Learning (Hodkinson and Hodkinson 2004)

	Intentional/ planned	Unintentional/ unplanned
Learning that which is already known to others	Planned learning of that which others know	Socialization into an existing community of practice
Development of existing capability	Planned/ intended learning to refine existing capability	Unplanned improvement of ongoing practice
Learning that which is new in the workplace (or treated as such)	Planned/ intended learning to do that which has not been done before	Unplanned learning of something not previously done

and Malcolm position is implausible. Is there available a better response to this problem? There is. Long ago Wittgenstein (1953) established that the fact that a distinction is susceptible to unclear borderline cases, does not invalidate the applicability or value of the distinction to typical cases. For instance, even in disciplines characterized by precision, there are perfectly useful distinctions that include seemingly intractable borderline cases, such as living/nonliving. Though there are no established boundaries, living/non-living continues to be a useful distinction. As (Glock 1996, p. 100) summarizes the situation:

▸ For a concept to be useful, all that is required is that it is defined for some cases, so that some things would definitely fall under it, and others definitely would not.

But the informal learning/formal learning distinction, as defined in this *Encyclopedia* clearly meets this requirement. So, the ongoing question is not whether it is possible to consistently distinguish informal learning and formal learning. Rather, the question is whether the distinction proposed here is the most useful, or whether other ways of making the distinction might prove to be more useful for particular purposes.

Important Scientific and Research Open Questions

On the one hand, both at the policy level and in society generally, there is insufficient recognition of the importance of informal learning. On the other hand, there is a tendency for policy makers to seek to formalize informal learning, e.g., assessment of prior learning, recognition of prior learning, etc. Such well-intentioned initiatives reflect the taken for granted assumption that for learning to be respectable, it needs to be formalized. However, much of the best of informal learning eludes formalization. So too often attempts at formalization trivialize informal learning (Hager and Halliday 2006). Rather than a "one size fits all" approach to understanding learning, informal learning needs to be better appreciated so that policies can be developed that achieve a judicious balance of the formal and the informal.

Cross-References

▸ Experiential Learning Theory
▸ Formal Learning
▸ Learning as a Side Effect
▸ Learning from Life
▸ Learning from Work
▸ Life-Long Learning
▸ Socialization-Related Learning

References

Beckett, D., & Hager, P. (2002). *Life, work and learning: Practice in postmodernity.* London: Routledge.

Billett, S. (2002). Critiquing workplace learning discourses: Participation and continuity at work. *Studies in the Education of Adults, 34*(1), 56–67.

Colley, H., Hodkinson, P., & Malcolm, J. (2003). *Informality and formality in learning: A report for the learning and skills research centre.* London: Learning and Skills Research Centre.

Eraut, M. (2000). Non-formal learning, implicit learning and tacit knowledge. In F. Coffield (Ed.), *The necessity of informal learning.* Bristol: The Policy Press.

Glock, H.-J. (1996). *A Wittgenstein dictionary.* Oxford: Blackwell.

Hager, P., & Halliday, J. (2006). *Recovering informal learning: Wisdom, judgement and community.* Dordrecht: Springer (Reissued as a paperback in 2009).

Hodkinson, P., & Hodkinson, H. (2004). The complexities of workplace learning: Problems and dangers in trying to measure attainment. In H. Rainbird, A. Fuller, & A. Munro (Eds.), *Workplace learning in context* (pp. 259–275). London: Routledge.

Stern, E., & Sommerlad, E. (1999). *Workplace learning, culture and performance.* London: Institute of Personnel and Development.

Wittgenstein, L. (1953). *Philosophical investigations (1967, 3rd edn.).* Oxford: Blackwell.

Information and Communication Technology Enhanced Education

► Integrated, Multidisciplinary, and Technology-Enhanced Science Education

Information Classification

► Knowledge Organization

Information Gathering and Internet Learning

SASKIA BRAND-GRUWEL
Centre for Learning Sciences and Technologies, Open Universiteit Nederland, DL Heerlen, The Netherlands

Synonyms

Information literacy; Information seeking

Definition

To gathering information and learning from different internet sources, one must be able to solve information-based problems. An information-based problem is a problem that only can be solved by searching information because there is a gap between prior knowledge and the required knowledge to accomplish the (learning) task successfully. Brand-Gruwel et al. (2005) introduced the notion of Information Problem Solving (IPS; see, also, Eisenberg and Berkowitz 1990) and defined IPS as the ability to solve information-based problems; one must be able to identify information needs and define the problem, to locate corresponding information sources, to extract and organize relevant information from each source, and to synthesize information from a variety of sources into cogent, productive uses.

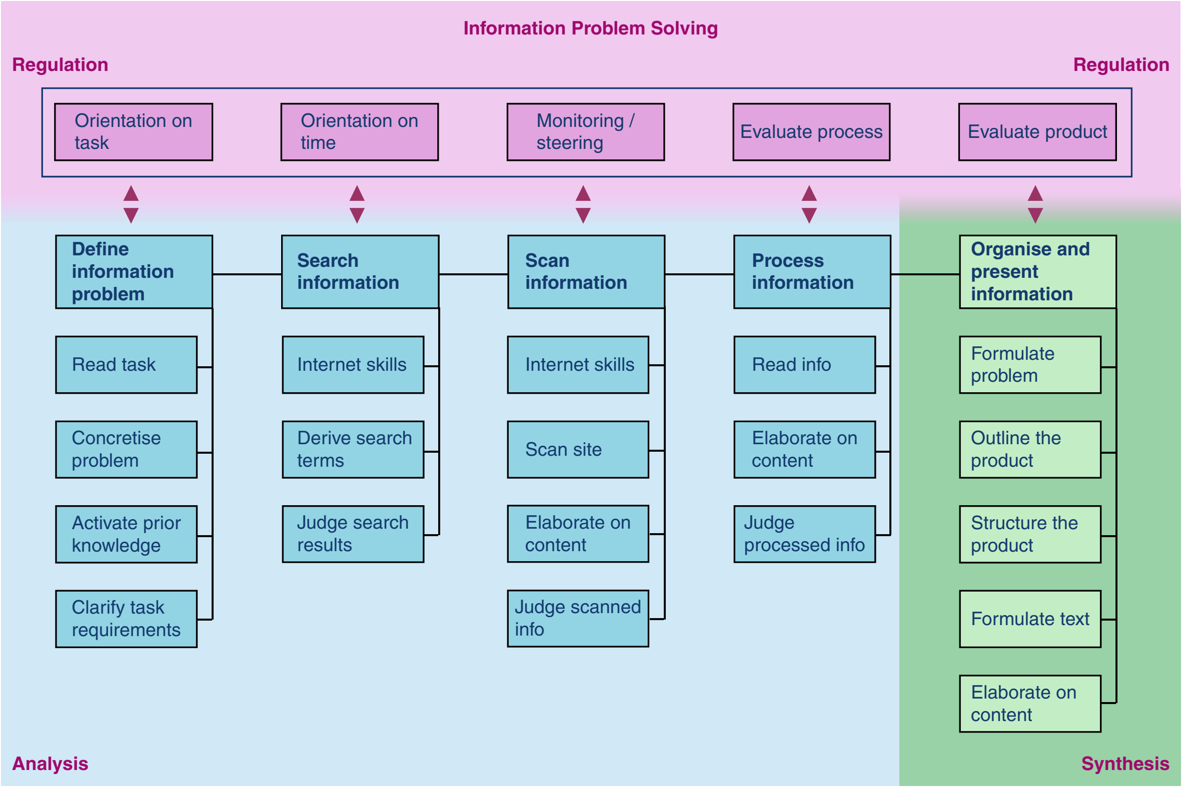
Theoretical Background

With the rising use of electronic information resources in everyday life and for educational purposes, researchers devoted more attention on unraveling the process of establishing meaning out of complex documents that learners will encounter when accessing the World Wide Web to learn out about a specific topic. Up to now, research on the IPS process has resulted in a large body of knowledge. Many researchers in library, information, and educational sciences have examined behaviors and skills associated with information use. Considering this research, one could conclude that different well-studied models are created. The model of Brand-Gruwel et al. (2005) contends that IPS can be decomposed into five constituent skills. These skills, which are meant to be executed in iterative cycles, are: (a) Define information problem; (b) Search information; (c) Scan information; (d) Elaborate information; and (e) Organize and present information. While executing these skills in an iterative way, regulation of the process is essential (for a comprehensive description of the model, see Brand-Gruwel et al. 2005). The IPS-model depicting the constituent skills and the subskills is visualized in Fig. 1.

The constituent skill *Define information problem* will always be performed at the beginning of the IPS process. This skill is important in order to get a clear insight into the problem. Without a good problem definition, the problem becomes hard to solve, and answers may not be adequate. While defining the problem, the main question and sub-questions are formulated, requirements are taken into account, and prior knowledge on the subject matter must be activated.

When performing the skill *Search information*, one has to select a search strategy, specify search terms, and judge the websites given in a hit list. There are several search strategies that can be used while searching information on the WWW. The three most common used strategies are: (a) using a search engine, (b) typing an address (URL) in the browser, and (c) browsing by following links. When using the first strategy, an important sub skill is specifying the search term(s). These terms are entered in a search engine, and the results (hit list) have to be judged on quality, relevance, and reliability.

The site that is opened after a search will be read globally (*Scan information*) to get an idea of the kind and the usefulness of the information. While scanning, one can elaborate on the content and combine the information with previous knowledge or other information found. When information is useful, it can be stored by for instance using bookmarks.



Information Gathering and Internet Learning. Fig. 1 Information problem-solving model

As opposed to scan information, the constituent skill *Process information* involves deep processing. The goal is to reach a deep understanding of the information or construct knowledge (learning), and to reach an integration of the different pieces of information found on the internet and relevant prior knowledge. Elaboration is an important aspect and can be expressed by analyzing, selecting, and structuring information. Especially for selecting information, criteria for judging the usefulness and quality of information are important.

The first four skills are part of the analysis phase of the IPS process. *Organize and present information* is part of the process that can be described as the synthesis. All the information will be combined, and the information problem can be solved. Making the product as required in the (learning) task is the goal or outcome of this constituent skill.

As can be seen in Fig. 1, *Regulation activities* will be carried out during the entire IPS process. Especially, with the WWW as an extensive source of information, a strong appeal to peoples' regulation ability is made. Regulatory aspects, such as orientation, monitoring, steering, and evaluation, play a key role in the execution of the skill. One needs to articulate a plan for how to solve the information problem. During the process, they have to monitor, steer, and check if the proposed plan is still the right one or decide if changes in the approach are needed. When a process is regulated well, it will have the character of a "goal-directed approach.". In this approach, the interaction with the information will be guided through an overall plan, while in the "data-driven approach" based on information found a plan (mostly incoherent) develops.

Research shows that many students are not able to solve information-based problems successfully. In a research overview Walraven et al. (2008), it is concluded that young children, teenagers, and adults do especially have problems *evaluating the trustworthiness of sources and information* in terms of relevance and reliability. These evaluation processes receive particular relevance when searching information on the Internet, where traditional gatekeepers of credibility, such as editors, are missing. Especially when it comes to health information provisions, it has frequently been reported that documents contain flawed or strongly biased information. In a special issue edited by Stadtler and Brand-Gruwel (in press), different studies on how students of different ages evaluated multiple (hypertext) document are addressed and, also, influencing factors as epistemological beliefs, prior knowledge, and also the ability to make use of textual cues in hypertext are described. Prior domain knowledge does have an impact on students' evaluation behavior in a sense that students with low prior knowledge do trust less trustworthy sources and do not differentiate between relevant and irrelevant criteria when judging the trustworthiness of sources. Metatextual knowledge or knowledge about the functions of structural features of a text, such as headings, paragraphs, or hyperlinks is of importance. Students tend to rely on lexical and typographical cues when assigning relevance, with relatively less consideration for deeper semantic cues. Also, epistemic beliefs are related to how people evaluate information and sources. In this sense, the materials retrieved in Web search function as a mediator. If conflicting information is found, this has an impact on people's confidence that they found an appropriate answer. It can be concluded that constructing meaning from multiple sources and especially when those sources are made up of hypertext and include conflicting information involves complex cognitive processes (see also Rouet 2006).

Taking these research results into account, it can be concluded that students must learn to solve information-based problems and must learn transferable strategies. Guidelines for designing instruction promoting the development of the complex cognitive skill of information problem solving are therefore needed. Different studies in different domain and with different kind of students are conducted to study effects of different methods and tools to support the process of IPS or certain constituent skills or the regulation of the process (see for different studies the special issue instructional support for IPS of Brand-Gruwel and Gerjets (2008)). Instructional and support methods can be grouped based on several features: the way the instruction is offered (either embedded in the curriculum or as a separate course); the way the instruction is followed by participants (individually or collaboratively), tools used during the instruction, and the skills addressed in the instruction. It shows (Walraven et al. 2008) most of the methods found were stand-alone courses for individual use. Tools used differed from a web-based portals or computer applications, to worked-out examples and visualizations, to worksheets, to paper material only. However, effectiveness of different methods has not been established without doubt. More research is needed to gain more insight in how IPS processes best can be fostered.

Important Scientific Research and Open Questions

In future research, fine-gained experiments should focus on unraveling the IPS processes involved in different circumstances and go into the interrelations of the influencing factors as epistemological beliefs, prior and metatexual knowledge, etc. More insight in how these processes and factors interact and are related can give input for design more adaptive instruction. Research on how the instruction and the learning environment can be adapted to the learners need and support the process and not hampering it is of importance.

Moreover, research methods used to gain insight into cognitive processes have become more sophisticated, and methods such as eye tracking and cued retrospective reporting (using eye movements as cue) have proven to be successful besides the often used thinking aloud method and the use of log files analysis. The added value of the use of more sophisticated research methods must in the future be addressed.

Cross-References

► Cognitive Learning
► Knowledge Acquisition: Constructing Meaning from Multiple Information Sources
► Problem Solving
► Twenty-First-Century Skills

References

Brand-Gruwel, S., & Gerjets, P. (Eds.). (2008). Instructional support for enhancing students' information problem solving ability [special issue]. *Computers in Human Behavior, 24*(3).

Brand-Gruwel, S., Wopereis, I., & Vermetten, Y. (2005). Information problem solving by experts and novices: analysis of a complex cognitive skill. *Computers in Human Behaviour, 21*, 487–508.

Eisenberg, M. B., & Berkowitz, R. E. (1990). *Information problem-solving: the big six skills approach to library and information skills instruction*. Norwood: Ablex.

Rouet, J. F. (2006). *The skills of document use*. New Jersey: Lawrence Erlbaum.

Stadtler, M., & Brand-Gruwel, S. (Eds.). (in press). Solving information-based problems: searching, selecting and evaluating information [Special issue]. *Learning and Instruction.*

Walraven, A., Brand-Gruwel, S., & Boshuizen, H. P. A. (2008). Information problem solving: A review of problems students encounter and instructional solutions. *Computers in Human Behavior, 24*, 623–648.

Information Integration

► Explicit and Procedural-Learning-Based Systems of Perceptual Category Learning

Information Literacy

► Information Gathering and Internet Learning
► Learning in Information-Rich Environments

Information Organization

► Knowledge Organization

Information Processing

► Learning by Chunking

Information Processing Theory

Theoretical perspective that focuses on specific mental processes involved in learning.

Information Seeking

► Information Gathering and Internet Learning

Information Transferring

► Intelligent Communication in Animals

Information Transmission

► Communication Theory

Information-Processing Approach

► Human Information Processing

Infotainment

► Children's Learning from Television
► Edutainment and Learning

Ingenuity

► Creativity and Its Nature

Inhibition and Learning

Luis Gonzalo De la Casa
Department of Experimental Psychology,
University of Seville, Seville, Spain

Synonyms

Absence of a consequence; Association; Change in behavior; Experience; Retention of responses

Definition

Learning is perhaps the most significant way in which organisms having a nervous system adapt their behavior to changes in the environment. The most common definitions of learning include, as features, that learning produces a relatively permanent *change in behavior* resulting from *experience* with certain stimuli or responses, and that the output of learning is not necessarily expressed in observable behavior (see, for example, Domjan 2003). Because of the complexity of the environment and the limits in processing capacity of organisms, the learning process can result in a new *association* between a stimulus (or a response) with a consequence or in an *association* between a stimulus (or a response) with the *absence of a consequence*. The first *association* results in the addition of new responses to the existing repertoire, and the second in the *retention of responses* in certain circumstances, this latter process being called inhibition.

Theoretical Background

People often assume that the sole function of learning is to add new representations and/or behaviors to the organism's repertoire (or to reorganize already existing representations or behaviors). However, a great portion of our adaptation to the environment involves learning of situations in which *not* responding is the most appropriate behavior. In these inhibitory learning situations, the content of learning involves the absence of a particular consequence. One of the pioneers in the study of inhibitory learning was the Russian physiologist Ivan Sechenov (1829–1905). In his book entitled ► Reflexes of the Brain (1863/1965) he highlighted the relevance of inhibitory mechanisms for the explanation of all responses, including human behavior, in terms of reflexes. In particular, by proposing the existence of inhibitory centers in the brain that acquire control over behavior as a function of experience, Sechenov overcame the challenge of explaining the supposed voluntary control of behavior that occurs, for instance, when a person keeps his or her hand next to a fire despite the reflexive tendency to pull it away.

However, it was Ivan P. Pavlov (1849–1936), another Russian physiologist, who in his extensive research on the phenomenon of classical conditioning discovered a type of learning in which a stimulus becomes a predictor of the absence of a consequence (Pavlov 1927). Such learning resulted in an inhibitory connection that suppressed the Conditioned Response (CR). The procedure used by Pavlov, which today is known as the standard conditioned inhibition procedure, entails establishing an excitatory connection between a CS1 and an Unconditioned Stimulus (US) – for instance, a sound that is paired with food – and interspersing these trials with ones in which the CS1 is presented together with a new stimulus, CS2 (for instance, a light), but without the US. This procedure results in the acquisition of an excitatory connection between the CS1 and the US, such that the sound becomes a predictor of food, and the acquisition of an inhibitory connection between the CS2 and the US, such that the light signals the absence of food. The consequence of this type of learning is that CS1 will produce an excitatory conditioned response – for instance, the tone will elicit a strong salivary response – while CS2 will produce an inhibitory conditioned response, that is, no salivation will occur.

Despite the clear relevance of inhibitory processes, most studies on learning processes that took place during the first half of the twentieth century focused on excitatory learning, that is, learning that results in new explicit behavior (Boakes 1984). It was not until the 1960s that inhibitory learning became a topic of great interest in behavioral psychology. Some prominent issues during this time concerned the type of procedure used for the establishment of inhibitory learning, and the way in which the learned responses should be measured.

Regarding the procedure, in order to establish inhibitory conditioning, a necessary precondition is that excitatory conditioning has occurred first. After all, how can we learn that something does not appear, if we have not first learned to expect its appearance? For example, a child cannot learn that he will not receive candies from his parents if he has never received any candy in the past. Likewise, it is impossible to know that white clouds signal the absence of rain if we have never experienced rain before. Clearly, a context of prior excitatory learning is necessary for inhibitory learning to occur. This excitatory context can be the presence of a specific stimulus that in the past signaled a consequence (as in the case of the standard conditioned inhibition procedure, described earlier), or it can be the odors, sounds, lights, etc., that made up the environment where the learning took place. For example, if a CS and an US are presented explicitly unpaired, such that the two stimuli never temporally coincide, contextual cues will become associated with the US, while the CS will signal the absence of such US. This so-called "explicitly unpaired" procedure can be seen for instance when a child is afraid of going outside, where other kids have been aggressive toward him, except when his father – the inhibitory CS signaling the absence of danger – agrees to accompany him. Another procedure producing an inhibitory association is known as "differential inhibition." In this procedure, a CS1 is presented together with the US, in alternation with trials in which a CS2 is presented alone. This treatment results in an inhibitory association between the CS2 and the US. For example, in bird species in which the female is the one who brings food to the nest, while the male never does, the gaping response of babies occurs in the presence of the mother, but it is inhibited if only the father is present.

Regarding the measurement of an inhibitory response, it can be directly assessed if the response is bidirectional in nature (in a common example from the animal laboratory, a light indicating the presence of food elicits the response of approaching the feeder, considered an excitatory response, whereas a tone indicating the absence of food produces the response of moving away from the feeder, considered an inhibitory behavior). However, the inhibitory response involves frequently the absence of a particular behavior. Thus, for instance, if we use the salivary response to measure an association, the inhibitory response would be the absence of salivation. The problem in such cases is that it is impossible to directly know whether the absence of responding is due to inhibitory learning, or instead simply due to no learning at all. To solve this problem, indirect techniques have been developed for the measuring of inhibitory responses. Specifically, Rescorla (1969) proposed the Summation test and the Retardation test to quantify the intensity of an inhibitory response. In the Summation test, an excitatory CS with a highly predictable conditioned response is presented together with a presumed inhibitory stimulus. If the stimuli compound reduces the magnitude of the conditioned response in relation to what would be expected from the excitatory stimulus alone, we can conclude that the added stimulus is in fact inhibitory. In the Retardation test, the time course of learning observed when the presumed inhibitor and an US are paired together is compared with the time course observed when a neutral stimulus and the US are paired. If conditioning occurs more slowly in the former case, then we can conclude that the presumed inhibitor indeed has inhibitory properties.

In short, appropriate behavior consists not only of active and observable motor responses, but rather these responses must be balanced with those that sometimes are inappropriate and should be inhibited. This intricate balance, which unfolds continually based on our assessment of environmental circumstances, is what produces adaptive behavior.

Important Scientific Research and Open Questions

As we have highlighted, in order for behavior to adapt to the continuous changes in the environment, excitatory and inhibitory activity must be in balance with each other. To achieve this balance, it is essential that the processing system not be overloaded with unnecessary information. Preventing information overload in turn requires mechanisms for the selective attention of stimuli intended to select which stimuli must be attended at any given moment based on their potential importance. Thus, learning on stimulus irrelevance seems to be essential for an adequate interaction with the environment, and it involves some kind of inhibition by which we ignore stimuli that in the past have not been followed by relevant consequences (see, for a review, Lubow and Weiner 2010). From this perspective, a learning process on the relevance of stimuli is necessary for excitatory and inhibitory learning processes occur appropriately. Psychologists have proposed a number of explanations for how ► inattention to irrelevant stimuli might develop, some based in attentional perspectives assuming that attention directed to stimuli is proportional to the degree to which they predict meaningful consequences, and others based in associative theories considering that stimuli lose relevance as a function of repeated association with the lack of consequences or by means of context associations. In any case, a complete explanation of behavior may only be achieved once we have identified the processes that underlie inhibition, processes that affect not only learning but also other psychological processes such as attention.

Cross-References

► Animal Learning and Intelligence
► Associative Learning
► Latent Learning
► Measures of Association
► Pavlov, Ivan P. (1849–1936)

References

Boakes, R. A. (1984). *From Darwin to behaviourism: Psychology and the animal mind*. Cambridge: Cambridge University Press.

Domjan, M. (2003). *Principles of learning and behavior* (5th ed.). Belmont: Thomson/Wadsworth.

Lubow, R. E., & Weiner, I. (2010). *Latent inhibition: Cognition, neuroscience, and applications to schizophrenia*. New York: Cambridge University Press.

Pavlov, I. P. (1927). *Conditioned reflexes* (trans: Anrep, G. V.). London: Oxford University Press.

Rescorla, R. A. (1969). Pavlovian conditioned inhibition. *Psychological Bulletin, 72*, 77–94.

Sechenov, I. M. (1965). *Reflexes of the brain*. Cambridge: MIT Press (Originally published, 1863 ed).

Inhibitory Conditioning

► Conditioned Inhibition

Inhibitory Learning

► Extinction Learning
► Neural Mechanisms of Extinction Learning and Retrieval

Initial State Learning

Jian-Xin Xu
Department of Electrical and Computer Engineering, National University of Singapore, Singapore

Synonyms

Dynamic mapping; Initial state learning; Learning algorithms; Static mapping

Definition

The aim of initial state learning is to establish a learning mechanism, which can be modeled as a mapping $M : x \to y$, where $x \in X$ denotes an input or a stimulus, and $y \in Y$ denotes the corresponding output or response. X denotes a set of inputs or an input space, and Y denotes a set of outputs or an output space. In physiology or brain science, such a mapping is achieved through a group of neurons. In psychology, such mapping is achieved through a short-term or long-term memory. In computer science, such a mapping is formed by a rule base, such as a Q-table, or an artificial neural network. In system and engineering, such a mapping is described by static function or dynamics.

Theoretical Background

A learning process is to establish the mapping M associated with the input space X and output space Y. In classical conditioning evidenced by Pavlovian experiment or in general procedural learning, the mapping M is evolved to link stimuli X with salivation Y. In brain science, the mapping is the link between the sensory inputs and cortical responses in the central nervous system (CNS) (Carpenter 2002). In computer science such as the reinforcement learning, the mapping M is a decision-making Q-table established through rewards. The input X of the Q-table is from the environmental states, whereas the output is a suitable action from the action space Y. In robotic motor-skill learning, the mapping M is an internal model that is formed through repetitively updating a central pattern generator (CPG) (Kawato 1999). The input X is a reference or command signal, and the output Y is a control signal profile that drives robot actuators to perform the expected movement.

The essence of the initial state learning is to establish or evolve the mapping M, either using prior knowledge directly or using progressively acquired knowledge. A learning task may be either time dependent or independent. The initial state learning for the former is to learn a static mapping, and for the latter is to learn a dynamic mapping.

With prior knowledge, the mapping can be obtained through repeated learning or training. Denote X_s and Y_s the subsets of X and Y that are available *a priori* before learning, for instance the samples of the input-output pairs. Various learning algorithms have been developed. A representative is the backpropagation learning algorithm that tunes the weights of a multilayer perceptron (MLP) network such that the MLP can link an element in X_s to an element in Y_s. The learning process is conducted progressively in the sense that input-output pairs are fed into the learning mechanism either in an ordered sequence or in a randomized sequence. Weights learning is carried out in sequence from output to input layers, while the weights of the same layers are updated concurrently.

The effectiveness of the learned mapping, M, depends on the abundance of the prior knowledge. Rigorously speaking, the mapping M is able to capture the connections between the inputs X and outputs Y, if X_s and Y_s are dense in X and Y, respectively.

In system identification, the abundance of the prior knowledge is known as the persistent excitation, which requires all modes in the mapping M being excited or visible during training.

When the mapping M is temporally dependent, that is, dynamical in nature, the learning process becomes more sophisticated. A major factor that leads to a temporally varying mapping is the incorporation of memory elements in learning mechanisms. For instance, an output signal is temporally related to not only the present input but also the past inputs. A state-time-dependent mapping, such as recurrent neural networks (RNN), autoregressive moving average models, Liquid State Machines (LSM), or in general a set of parameterized differential-difference equations, can be written as $M(t, s, p)$, where t denotes the temporal factor, s denotes a set of internal states, and p denotes a set of tuning parameters that determine the characteristics of the mapping.

In an RNN, $M(t, s, p)$ is expressed as a set of first-order differential equations. The task of the initial state learning is to determine the parameters p, such that the mapping $M(t, s, p)$ can produce various desired behaviors, for instance, the behaviors of *C. elegans* in its fundamental activities such as food attraction and toxin avoidance. The real-time recurrent learning algorithm can be applied to learn parameters p.

The LSM is a type of spiking neural networks inspired by cortical microcircuits (Maass et al. 2002). The LSM is able to take into account the temporal structure of the input signal because it possesses a fading memory, which results from recurrent connectivity between excitatory neurons, the dependence of synaptic efficacy on recent input history, and the exponential-decay of membrane potential changes induced by synaptic inputs. Thus LSM has the great potential to efficiently memorize and classify data with strong temporal features owing to its inherent time-dependent dynamics. LSM adopts a regression type of learning algorithm to tune parameters p for readout neurons, as a result a mapping $M(t, s, p)$ is achieved.

Note that the aforementioned learning is based on the availability of adequate prior knowledge. Without adequate prior knowledge, a learning agent has to seek alternative initial state learning approaches, such as on-line learning. The aim of on-line learning is to improve the mapping M progressively so as to ultimately capture the precise input–output relationship.

Most initial state learning problems can be formulated as parametric learning problems. The parametric learning is a model-based approach, in which the model or the structure of mapping $M(t, s, p)$, for instance the topology of an artificial neural network, is assumed known or prespecified. The sole undetermined is the set of parameters p, for instance the set of neural weights or synapses. As such, the learning algorithm can be described by an updating law:

$$w_{k+1} = w_k + \gamma_k e_k \tag{1}$$

where w_k denotes the vector-valued weights at the kth moment, γ_k is a learning gain matrix, and e_k is an innovation or correction term. As a result, the learned mapping is $M(t, s, w_k)$, which converges to the true mapping $M(t, s, p)$ as far as w_k approaches p when k evolves.

One critical issue in initial state learning is the learning convergence property. For any learning algorithms taking the form Eq. 1, the learnability of p by w_k depends on the gradient of the mapping

$$\frac{\partial M}{\partial p},$$

and γ_k can be chosen as closely as the inversion of the gradient. In such circumstances, it is necessary that the gradient is nonsingular, in other words, a variation in p must yield a variation in $M(t, s, p)$. If the variation of p does not result in any variation in $M(t, s, p)$, we can simply choose $p = 0$ while the mapping property remains invariant, hence $M(t, s, p) = M(t, s, 0) = M(t, s)$ or the mapping is irrelevant to p.

When the gradient is unavailable, an alternative is to randomly generate γ_k, which decides the learning direction. By trial and error selection, the learning can still be performed except for the loss of efficiency due to the lack of the prior knowledge (Spall 2003).

Nonparametric learning, complementary to the parametric learning, is to build up the mapping M directly without using any model. From dataset or signals, the mapping M can be expressed in the form of a data structure. In the field of computational intelligence, evolutionary computation methods such as genetic algorithm develop a mapping M, either static or dynamic, through randomized optimization or randomized learning. Nonparametric learning can also be conducted for deterministic processes, for instance in system control, where the iterative learning directly links a given reference to the desired control action profile stored in memory (Xu and Tan 2003). A major advantage of nonparametric learning is the degree of freedom in the construction of the mapping M, which can be solely data driven and no prior knowledge is required for the selection of a model for the mapping M. On the other hand, without a model the gradient information is often unavailable or imprecise. As a consequence the learning efficiency would drop and learning becomes more trial and error.

Important Scientific Research and Open Questions

While the gradient information decides how a mapping can be learned, a more fundamental issue is regarding what kind of mapping can be learned.

In human motor-skill learning, CPG is a widely adopted concept and a hypothesis from CNS research. According to the theory of CPG, when a command is sent to activate a CPG, the CPG generates a sequence of control signals to coordinate actuation parts such as muscles for an intended motion. The mapping, in this circumstance, can be written as $M(u)$ for a static mapping or $M(t, s, p, u)$ for a dynamical mapping, where u denotes an exogenous input, such as a stimulus to CNS, or a command to a robot.

To establish such a CPG, however, the learner has to try the intended motion repetitively till the same motion can be produced with the required precision. In other words, through learning, the CPG has eventually captured and stored all necessary motorneuron signals to drive muscles. Likewise, to memorize a new word, the learner has to read and use the word repetitively, so that the word can be coded into the long-term memory in CNS. During the learning process, it is important that the learning task, either a motion or a word, remains invariant. It would confuse the learner if the motion pattern or the word keeps varying during the learning process.

What we can conclude from learning processes is the invariance principle: the mapping M should be invariant during the learning process, so that human or machines can learn the mapping. In system and control, this invariance principle is formulated as the internal model principle (Francis and Wonham 1976), and subsequently extended to the field of learning control. However, it remains an open issue for the extension of the invariance principle or internal model principle to computer science (e.g., machine learning), the brain science (e.g., CPG), psychology (e.g., short-term and long-term memory), and science and engineering (e.g., robotics).

Cross-References

► Iterative Learning Control
► Neural Network Assistants for Learning
► Neuropsychology of Learning

References

Carpenter, R. H. S. (2002). *Neurophysioplogy.* London: Hodder Arnold.

Francis, B. A., & Wonham, W. M. (1976). The internal model principle of control theory. *Automatica, 12*(5), 457–465.

Kawato, M. (1999). Internal models for motor control and trajectory planning. *Current Opinion in Neurobiology, 9*(6), 718–727.

Maass, W., Natschlager, T., & Markram, H. (2002). Real-time computing without stable states: a new framework for neural computation based on perturbations. *Neural Computations, 14*, 2531–2560.

Spall, J. C. (2003). *Introduction to stochastic search and optimization.* Hoboken: Wiley-Interscience.

Xu, J.-X., & Tan, Y. (2003). *Linear and nonlinear iterative learning control.* Germany: Springer.

Initiation-Response-Evaluation (IRE) Sequence

Is a three-part communication pattern that begins with the teacher addressing the student with a question or request, continues with student's response, and ends with the teacher's evaluative feedback. This sequence has been found to be, at least till recently, the dominant form of learning–teaching interaction in schools and also in many informal settings.

Innateness Controversy

► Collective Development and the Learning Paradox

Innovation and Learning Facilitated by Play

Poul Kyvsgaard Hansen
Center for Industrial Production, Aalborg University, Aalborg Oest, Denmark

Synonyms

Experimenting; Hand–brain connection; Prototyping

Definition

In this particular context, play refers to the state of mind where people are playful. Playful in the sense of being completely open-minded and able to construct and rearrange knowledge. This state of mind is essential when children are learning but can also explain the state of mind that people are in when there are innovating or learning from their experiences. While it is natural for the child to enter this state of mind, it is more challenging for adults to bring themselves into such a state of mind. Reaching the state of playfulness is generally easier if some element of physical artifact is involved. This is explained by the complex interplay between the hands or body and the brain.

Theoretical Background

The essence of innovation is a break in our perception of a particular issue (product, process, service, etc.). When the break in perception has emerged, it becomes so obvious that it is difficult to imagine that it did not exist before. However, before the break in perception, the issue at focus is a truly complex problem. Complex in the sense, that the relationship between cause and effect can only be perceived in retrospect but not in advance. One particular problem in handling complex problems is the articulation (to express what is not yet existing) and sharing (to communicate this to others). In many cases, we restrict ourselves to use the spoken and written language as means of articulation. However, the spoken language has a large number of limitations. Therefore, efficient communication needs various supplements to ensure both richness and nuances in the process of articulation and sharing.

In this process, the spoken language is supplemented with nonverbal communication (body language, voice tone, facial expression, etc.) and with physical artifacts created as an integrated part of the process. Many of the approaches involving physical artifacts include elements of play because the psychological state of people in play is largely open-minded and, thereby, more receptive to both learning and perception (Gauntlett 2007).

The creation of physical artifacts as an integrated part of the process builds on the complex interplay between the hands and the brain. In neural sciences, this interplay has been communicated in a more popular way by a grotesquely disfigured human body, named “Homunculus.” Homunculus is a physical representation of the portion of the human brain that is responsible for exchange of sensory information from the different parts of the body (Wilson 1998). The resulting image is a grotesquely disfigured human with disproportionately huge hands (and fingertips in particular), lips, and face in comparison to the rest of the body. Because of the fine motor skills and sense nerves found in these particular parts of the body, they are represented as being larger on the homunculus. A part of the body with fewer sensory and/or motor connections to the brain is represented to appear smaller.

Though the Homunculus is a gross oversimplification of the human neural system, it is useful in order to understand why the process of building and engaging with our hands and fingers stimulate our brain and thereby our imagination. Many contributions and ideas from the fields of psychology and behavioral science support these experiences and empirically documented observations:

- Constructivism – a theory of knowledge developed by Jean Piaget, his colleagues, and his institute in Geneva, Switzerland.
- Constructionism – a theory of learning developed by Seymond Papert and his colleagues at MIT in Cambridge Massachusetts, USA.

Michael Schrage (Schrage 2000) documents many aspects of using physical artifacts for improving innovation processes and points to a number of central characteristics:

- When talented musicians improvise, you don't look inside their minds; you listen to what they play. When talented innovators innovate, you don't listen to the specs they quote. You look at the models they've created.
- The challenge of converting uncertainty into manageable risks or opportunities explains why serious play is often the most rational behavior for innovators.
- Serious play is about improvising with the unanticipated in ways that create new value.
- Prototypes engage the organization's thinking in the explicit. They externalize thought and spark conversation.
- Prototypes force confrontation with the tyranny of trade-offs.
- The conventional wisdom that "innovation processes" drive prototype development is misleading. Empirical observation of organizations with effective innovation cultures confirms just the opposite: changes in prototypes and simulations drive the innovation process.
- Prototypes are machine tools for producing choice.
- Most companies have formal prototyping processes and informal prototyping cultures.

The physical involvement combined with the state of play also facilitates the high involvement of emotions in the process. Csíkszentmihályi outlines in his "Flow" theory that people are most happy when they are in a state of flow – a state of concentration or complete absorption with the activity at hand and the situation. The idea of flow is identical to the feeling of being in the zone or in the groove. The flow state is an optimal state of intrinsic motivation, where the person is fully immersed in what he or she is doing. This is a feeling everyone has at times, characterized by a feeling of great freedom, enjoyment, fulfillment, and skill – and during which temporal concerns are typically ignored (Csíkszentmihályi 1990).

Important Scientific Research and Open Questions

The research effort titled Constructionism initiated by Seymond Papert at MIT appears to touch on many of the ongoing research questions related to hand–mind relationships and involvement of play in innovation processes (Papert 1996). Constructionism is a way of making formal, abstract ideas and relationships more concrete, more visual, more tangible, more manipulative and, therefore, more readily understandable. At the core of the research effort is the notion that when we "think with objects" or "think through our fingers," we unleash creative energies, modes of thought, and ways of seeing what most adults have forgotten they even possessed.

Most of the ongoing research has focused on the individual. However, innovation processes are mostly collective processes. Howard Gardner (2007) has recently pointed to the area of team creativity as an important field that is been underestimated due to a research bias on the individual. Gardner questions whether our the ideas about creativity need to be refashioned to take into account the increasing number of projects and realms where the individual contribution seems less critical, the group mind more crucial. He points to improvisation as a critical concept in terms of bringing team creativity to the fore. To facilitate improvisation, he calls for appropriate methods that support the abilities to come to know individuals quickly, to forge a working relationship, and to handle issues of conflict and credit.

Cross-References

► Action Learning
► Collaborative Learning
► Collective Learning
► Flow Experience and Learning
► Games-based Learning
► Imaginative Learning
► Neuropsychology of Learning
► Play, Exploration, and Learning

References

Csíkszentmihályi, M. (1990). *Flow: The psychology of optimal experience.* New York: Harper & Row.

Gardner, H. (2007). *Five minds for the future.* Boston: Harvard Business School Publishing.

Gauntlett, D. (2007). *Creative explorations – New approaches to identity and audiences.* New York: Routledge.

Papert, S. (1996). *The connected family.* Atlanta: Longstreet Press.

Schrage, M. (2000). *Serious play – How the world's best companies simulate to innovate.* Boston: Harvard Business School Press.

Wilson, F. (1998). *The hand: How its use shapes the brain, language, and human culture.* New York: Pantheon Books.

Innovative Learning Environment(s)

► Playful Learning Environments: Effects on Children's Learning

Inquiry Environments

► Experimental Learning Environments

Inquiry in Learning

► Imaginative Learning

Inquiry Learning

HASAN CALISKAN
School of Communication Sciences, Anadolu University, Eskisehir, Turkey

Synonyms

Inquiry-based learning

Definition

Inquiry is defined as "a search for knowledge; an instance of questioning; and a systematic investigation of a matter of public interest." Inquiry learning, on the other hand refers to a learning process. It requires learners to get involved in the learning process so that they can search for knowledge by questioning and investigating the matters. A learning process usually begins with posing a question or a problem. Then learners try to generate strategies in order to investigate, collaborate, justify, and reflect on the solutions for the problem or answers to the question. They later communicate and share the conclusions.

Perhaps the old Chinese proverb "tell me and I forget, show me and I remember, involve me and I understand" best explains this type of learning. Because of the nature of the method, learners are not just passive consumers of the knowledge being taught, but instead they are actively trying to build an understanding of it so that they will use and share it in their real lives as they try to solve problems. By getting involved in a learning situation learners will have opportunities to develop skills for seeking appropriate answers to questions and issues throughout the learning process.

Inquiry requires a want or need for questioning or researching. In fact this need is an inherent aspect of people from the time they are born until they die. Children learn about their surroundings by making inquiries. They learn things, faces, relations, voices, and so on. A process of inquiry begins with gathering related information and data using one's senses. People may gather information by hearing, seeing, touching, tasting, and/or smelling and thus they may solve problems or answer questions using the information they have gathered. But most of the time there might not be just one correct solution to the posed questions or problems. Thus, it is important for learners to come up with the appropriate answers or solutions. Using this approach, learners will gain the inquiry skills and attitudes needed to solve problems and continue the quest for knowledge and understanding for their future learning.

Inquiry-based learning can be said to be the center and focus of carefully designed research activities for learners. The core idea here is that the activities involved in such research processes must be based on formulating and asking questions that will require critical thinking. By gaining and performing critical thinking skills, learners will be able to construct new learning or meanings that they will be able to reason with when asked. Another important aspect of inquiry learning is that at the end learners write, report, and share their thinking processes and conclusions. This approach is believed to cause better and enriched permanent learning experiences and skills for learners rather than having just shallow understanding of concepts and processes.

Theoretical Background

The inquiry-learning approach is not a new trend. As an instructional method it has its roots back in the 1960s when the discovery learning movement was in action. It was a kind of reaction to learners' passive receiver conditions in traditional settings. Being a form of active learning the inquiry-learning method concentrates on the extent to which learners will develop analytical and critical thinking skills rather than merely acquiring passive knowledge.

An inquiry-learning process is a learner-centered approach. It is the learners who conduct inquiry. Instructors, on the other hand, are responsible for the organization of different activities or settings using different inquiry models so that learners can undertake inquiries (Sandoval 2005).

It should be made clear that an effective inquiry process requires more effort than just asking questions. In order for an inquiry process to be effective, the process should require learners to convert the accumulated information and data into useful knowledge applying some complex processes. This depends on several factors such as a context, a framework, a focus, and different levels for the questions. It is obvious that any question should be bound to a context or framework so that it might make more sense for learners than just passing on a test or memorizing facts or events. Similarly, teaching materials or processes should also include relevant and enough contexts for the new information. Teachers, as guides, should facilitate learners to better grasp the information given in such contexts.

According to Wolf (1987), the majority of teachers think that they use questions in their teaching. But on the other hand, research findings show that these questions are mainly on the "knowledge" level. That is, learners are just required to repeat whatever they have just been taught. Questions that demand learners to infer, reason, form, or transfer the gained knowledge do not occur frequently in classrooms. Wolf further suggests five major types of question: inference, interpretation, transfer, hypotheses and reflection.

Inference questions require learners to go beyond the information given while the interpretation questions ask students to fill in the missing information. Transfer questions require learners to take their new experiences to new situations or circumstances and to use it there. Questions about hypotheses force learners to engage in predictive thinking. Finally, reflective questions require learners to question themselves, reflecting on their new learning experiences.

It is clear that learners' questions are very crucial for inquiry learning. Learners work together to solve problems rather than passively receiving direct instruction from teachers. In such an environment where learners search for solutions and answers to questions, the teachers' responsibility is to facilitate the learning and help learners discover the knowledge themselves instead of providing the knowledge as the only source of information.

There are a number of studies that can be viewed as the antecedents of the inquiry method. Piaget, for example, sees a child as a learner at the center of the learning process. In his cognitive development theory, Piaget insisted that a child is not a passive receiver of knowledge. Rather, he/she is actively gaining knowledge (Atherton 2011).

According to Dewey, as learners face and try to solve real-life problems in their learning processes they gain rich and permanent learning experiences. Thus, it should be made clear that learning activities will include real-life contexts and problems so that learners can engage in solving such authentic problems and thus develop higher-order thinking skills (Dewey 1938).

Vygotsky also does not perceive learners as passive consumers of knowledge. Rather, he emphasizes the importance of the interactions of learners with their environment. According to Vygotsky, learners' interactions with their surrounding culture, parents, and peers who are more skilled contribute significantly to a learner's intellectual development (Vygotsky 1978).

Freire, in his work, assumed that the most important and useful learning experiences are those that focus on the identification and resolution of real-life problems in learners' environments. Any learning situation should include such real-world experiences or problems so that learners can analyze the situations and formulate appropriate questions (Freire 1998).

In each of these approaches, as in the inquiry method, it is clear that the learners play an active role in the learning process. Having learners engage in such activities or processes during their learning will cause them to analyze, question, evaluate, and synthesize the information they are being exposed to.

Important Scientific Research and Open Questions

Inquiry learning has been one of the main teaching/learning approaches for quite a long time. It is not surprising that people give the method or process different names since the core idea is based upon learners' being active in the process as in so many other approaches. There are on the other hand advantages and disadvantages of this approach to learning.

Inquiry learning requires that learners are the active participants in the learning process. With students getting involved in the learning situation it is assumed that it will lead to a deeper understanding of the subject matter. Furthermore, it can also help with the attainment of higher-order thinking skills.

Meta-analyses have been conducted to investigate the effectiveness of the method on medical-school learners. The results indicated that the learners were motivated by the process and furthermore showed better problem-solving skills (Albanese and Mitchell 1993; Vernon and Blake 1993). Learners were also more active during the studies. The findings out of such studies indicate positive perceptions of learning environment, more confidence in problem solving, high motivation and interest, better self-esteem, and a better sense of autonomy about the inquiry-learning methods.

Hmelo-Silver et al. (2007) cite some studies that support the success of the constructivist problem-based and inquiry-learning methods. According to these researchers, learners showed significant gains over the control groups. They also talk about some studies in which inquiry-based approaches were effective for middle-school students comparing their performance on standardized tests.

Guidance rather than direct instruction is one of the key elements of inquiry learning. But on the other hand, it is the guidance element that is questioned in many studies. In their study, Kirschner et al. (2006) found that minimally guided instruction was less effective and less efficient than approaches with stronger emphasis on guidance of the student-learning process. As learners gain sufficiently high prior knowledge that provides internal guidance and thus confidence, the need for guidance begins to recede.

Perhaps, critiques toward Vygotsky for his approach to learning (especially for zone of proximal development and scaffolding) take their basis from such a perspective. Vygotsky has been criticized for his emphasis on collaboration and guidance by the view that if the level of guidance and collaboration is not balanced then learners may not take control of their learning when it is time to do so after getting used to receiving help from others. Controlling parents, for example, may cause children to show such behavior.

Critiques of inquiry learning generally report learners' feelings of frustration, uncertainty, and discomfort depending upon the nature of the process itself. As learners get used to passive traditional learning situations, they might feel uncomfortable when they are exposed to such ambiguous and open-ended learning situations especially when they are newcomers to the subject matter being taught.

Cross-References

► Active Learning
► Cooperative and Collaborative Learning
► Critical Learning Incidents
► Discovery Learning
► Experimental Learning Environments
► Multiple Intelligences and Learning Styles
► Open Learning
► Open Instruction and Learning
► Project-Based Learning
► Socio-Constructivist Models of Learning

References

Albanese, M. A., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine, 68*, 52–81.

Atherton, J. S. (2011). *Learning and Teaching; Piaget's developmental theory.* Retrieved April 29, 2011, from http://www.learningand-teaching.info/learning/piaget.htm.

Dewey, J. (1938). *Experience and education.* New York, NY, USA: Kappa Delta Pi.

Freire, P. (1998). *Teachers as cultural workers – Letters to those who dare each.* Oxford: Westivew Press. Retrieved March 31, 2011, from http://www.newfoundations.com/ GALLERY/Freire.html.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4), 634–656.

Vernon, D. T., & Blake, R. L. (1993). Does problem-based learning work? A meta-analysis of evaluative research. *Academic Medicine, 68*(7), 550–563.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, Massachusetts, London, England: Harvard University Press.

Wolf, D. P. (1987). *The art of questioning. Academic Connections, Winter*, pp. 1–7. Retrieved March 31, 2011, from http://www.exploratorium.edu/IFI/resources/workshops/.

Inquiry-Based Learning

► Action-Based Learning
► Inquiry Learning
► Learning by Doing
► Problem-Based Learning

Inquiry-Based Learning Environments

► Technology-Enhanced Learning Environments for Science Inquiry

Insight

Holistic, sudden comprehension of the parameters of a problem, supporting efficient solution.

Cross-References

► Tool Use and Problem Solving in Animals

Insight Learning and Shaping

Johan Lind, Magnus Enquist
Centre for the Study of Cultural Evolution &
Department of Zoology, Stockholm University,
Stockholm, Sweden

Synonyms

Insightful behavior; Successive approximation procedure

Definitions

Thorpe defined *insight* in his 1964 book "Learning and Instinct in Animals" as: "The sudden production of a new adaptive response not arrived at by trial behavior or as the solution of a problem by the sudden adaptive reorganization of experience."

Shaping is a powerful animal training method, described by B.F. Skinner, in which a novel behavior (target behavior) or a behavioral sequence is created. It works through successive steps of learning, where one desired behavior at a time is rewarded and learnt. This results in a shaped behavior or in a shaped behavioral sequence.

Theoretical Background

Complex behavior, or sequences of actions, that lead to particular goals, can be found in many animals. However, it is not possible from just observing such complex behavior to know whether they are a result of genetic programming or of different kinds of learning phenomena. Because the exact same behavior, for example, tool use, can arise through different mechanisms, we want to emphasize that on cannot judge any experiment or observation by the end result alone.

Insight learning and shaping refer to two learning processes giving rise to complex behavior. It is theoretically unclear how insight learning and shaping are different, and it is also problematic empirically how to distinguish between the two. Strong claims are common in the literature in both directions. Apparently seemingly intelligent behavior can arise in many ways. What an animal does can be easily observed, but to decide through what mechanism an animal reaches its decision is a task of much greater difficulty. Key to understanding is knowledge of an animal's previous experiences, its background. Herein lies a fundamental problem; how can one separate insight learning from shaping?

The question of what causes intelligent is of great interest for both scholars and the public. It is also an important question that can shed light upon the evolution of mental capacities in both nonhuman animals and humans.

Insight

The psychologist Wolfgang Köhler was interested in the mental capacities of our closest living relatives. In his 1925 book *The Mentality of Apes*, he asked the question whether apes "[...] behave with intelligence and insight under conditions which require such behaviour." He stood in stark contrast to contemporary behaviorists and argued that theory of "association psychology" could not account for apparently intelligent behavior in apes.

He observed captive chimpanzees (*Pan troglodytes*) that acquired food in, what Köhler argued, novel ways. Bananas hanging from the ceiling out of reach were plucked as a chimpanzee moved boxes present elsewhere in the cage to the spot right underneath the bananas. These boxes were subsequently used as ladders and Köhler argued that the chimpanzees solved problems by perceiving the components of the task in a new light; the relational perception of the food and the boxes were sufficient for a chimpanzee to solve a banana-in-the-ceiling-problem.

However, as the knowledge of chimpanzee behavior increased, other researchers argued that what Köhler observed could be explained by trial-and-error learning. Captive chimpanzees are often seen playing with sticks, manipulating them, biting and sticking them together. Such experiences were found to be necessary for chimpanzees to successfully solve problems equivalent to Köhler's experiments. Hence, how Köhler's chimpanzees managed to solve a wide range of problems could be understood through a process of trial-and-error learning combined with using previously successful behaviors (through stimulus generalization) in similar, but novel, situations. See also below how certain pre-training in pigeons allowed them to solve a similar task as Köhler's chimpanzees.

An early and influential claim of insight learning was Tolman's and Honzik's rat experiment. Rats navigating in mazes solved problems by producing novel responses that had not previously been reinforced. In contrast to the questionable novelty of how Köhler's chimpanzees solved their problems, the novelty of the rats' solutions was documented.

Many researchers have today reached the conclusion that animals can solve problems through insight learning, for example, many species of birds and mammals. In the 1997 book *Primate Cognition*, Tomasello and Call remark that "in their everyday use of tools, chimpanzees often show insight [. . .]."

However, despite nearly 100 years of research since Köhler performed his experiments and other researchers provided alternative explanations, the exact nature of insight learning is still elusive.

Trial-and-Error Learning and Shaping

When trial-and-error learning is studied in the laboratory, it is often called operant or instrumental conditioning. Then a researcher delivers a reward or a punishment after an animal has behaved in a certain way. Through this learning mechanism, an animal can learn the consequences of its own behaviors in the experimental setting.

Such conditioning is the base for a powerful method that can produce novel, and sequential, behavior which is called shaping. Shaping was identified by B. F. Skinner, and this method can be used to create novel behavior, or novel behavioral sequences, through successive reinforcement of behaviors which subsequently become more and more similar to the sought after target behavior.

It is possible to train a rat a specific sequence of actions. For example, first pull a string, then climb a ladder, and finally cross a small pool of water to receive a reward. A rat would have severe difficulties in solving this sequence on its own. But this is possible through shaping, which can be understood as sequential operant conditioning and was first described with the term *successive approximation procedure*. This method enables a trainer to teach animals specific behaviors or a sequence of behaviors. This widely applied methodology is used routinely in animal training, by both professionals and amateurs, and can also in some cases be used in modifying human behavior.

What Skinner showed was that by applying the method of shaping, animals can be taught novel behaviors. For example, pigeons can learn to reach food hanging out of reach from the ceiling by moving boxes and use them as ladders when put in the correct spot. That is, solving similar problems as those presented to chimpanzees by Köhler.

Importantly, shaping can also be said to occur in nature where individuals successively learn effective behavioral sequences. Irenäus Eibl-Eibesfeldt showed in a study 1963 how inexperienced squirrels gnaw and pry rather randomly when trying to open nuts. But through successive trial-and-error learning, their behavior becomes more and more efficient. Experienced squirrels open nuts easily by first gnawing a furrow on the side of the nut and then prying the nut open, thus breaking it in two halves.

Important Scientific Research and Open Questions

Theoretical Issues

First, we would like to point out that shaping relies upon mechanisms that are far from trivial. Animals are not so called stimulus–response (S-R) machines. An animal that only relies upon S-R learning will have great difficulties solving any task of even a limited sequential nature. Thus, the theoretical understanding of shaping is not satisfactory. We can also conclude that shaping is an effective, intelligent, method to explore the environment. Exploration is not random and through shaping behaviors can improve successively.

We also need better definitions – when does a behavior arise through shaping, when is it caused by insight learning? Shaping, often seen as a trivial method, might not be that simple a process as it is usually portrayed in the literature. Shaping is by definition a sequential process, and we think there is a gap in the knowledge of how sequential information processing works. To date, there exist no unambiguous criteria for distinguishing between these two mechanisms, and studies therefore still rely upon verbal arguments rather than solid methodology when exploring this issue. For example, studies in animal cognition often state that an animal's behavior arose "without overt trial and error." However, what "overt trial and error" means exactly is not known. It is difficult to define exactly how large the difference between two behaviors must be to invoke one explanation or the other. Perhaps there is no clear-cut boundary between these mechanisms?

Hence, vague explanations are unsatisfactory and do not help in elucidating the nature of insight learning in animals. Furthermore, exploration sets the stage for what an animal actually can learn through trial-and-error learning. Exploration itself is subject to learning, and how animal exploration is affected by training in general, and particularly shaping, is not well understood.

Another definitional problem is related to insight. There can be other behavioral mechanisms than insight that can potentially give rise to a "sudden production of a new adaptive response not arrived at by trial behavior." For example, animals can learn about their environment without any rewards. This is called latent learning and was shown in those early maze experiments which claimed that rats could solve problems through insight. Tolman and Honzik, in 1930, compared two groups of rats, one group which received rewards in the trials and a non-rewarded group. The rats that were rewarded showed a steady decline in navigational errors throughout the first ten trials, whereas the non-rewarded rats did not show such a decline in errors made in the same number of trials. But when rewards were introduced after the tenth trial, for the previously non-rewarded rats, they made just as few errors as the rats that had been rewarded throughout. This shows that learning had taken place even when rewards were absent. As shown by Tolman and Honzik, latent learning can give rise to novel behavior not arrived at by trial and error. Importantly, in contrast to insight, which depends upon a reorganization of experiences, there is no need for reorganization of experiences in latent learning. To control for latent learning, a clear documentation of individuals' experiences is needed. Again, this shows the importance of knowledge of individual animals' experiences for correct interpretations of test results.

One further phenomenon that can confound studies of insight in animals is generalization. Generalization depends strongly upon previous experiences and can be powerful for stimuli with which an animal has little previous experience. Stimulus generalization is a well-known phenomenon and vertebrates, and many invertebrates appear to generalize in the same way. What is more important for insight, but less well known, is generalization of rules. Animals have been shown to learn about relationships between events. If such rules are generalized, it is likely that apparently novel behavior can be elicited as a result. Importantly, animals have the capacity for coping with novel stimuli and situations by exploring their environment. How trial-and-error learning, or shaping in the laboratory, interacts with generalization to produce novel behavior is not well understood.

We conclude that both shaping and insight learning are effective because both processes limit individual's exploration thus increasing the precision of animals' behaviors.

Empirical Issues

If insight learning is an important mechanism in animal behavior, then we need a methodology that can distinguish between insight learning and shaping. A common methodology is that researchers subject their animals first to a training paradigm and then subsequently test them on a novel problem and measure whether the animals can solve the novel problem successfully. If the novel problem is different from the problems experienced during training, then insight is often concluded to be the mechanism through which the animal solved the test problem.

The key to distinguish between whether a behavior arises through insight or shaping is knowledge about an animal's previous experiences, its background. Hence, it is critical to quantify how the end result was achieved. Important differences are that behaviors arising from shaping are learnt successively, in steps, whereas animals capable of insight should be able to produce solutions to problem without having similar experiences to the test problem. For example, an animal should be able to reorganize information gathered in independent contexts, solve problems in many more different ways, and probably solve problems quicker than if the behavior has been acquired through shaping. One method to test insight would be to allow animals gather information about problems without having the opportunity to test different solutions. If it is assumed that insight takes time, as human thinking does, one prediction would be that animals allowed a longer time to process information should more quickly solve a problem at hand. Another way to distinguish between shaping and insight learning can be to use reinforcements to teach an animal a sequence of events. In a subsequent test, the animals can be given information that the sequence is no longer valid, the animal is thus forced to reorganize information to solve this novel problem and, if the animal uses insight, one should expect immediate correct responses in contrast to observing an extinction process and a relearning of the new solution to the problem.

We also want to highlight that many studies of insight learning in animals have used extensively trained animals. Some animals have even been trained for several decades, as, for example, the famous African Grey Parrot, called Alex, or several so called "encultured" apes. Great care needs to be taken when interpreting test results of such well-trained animals because of their extensive training.

Conclusion

In conclusion, demonstrating insight learning in animals is problematic because it is currently not known how different a test situation must be for shaping or operant conditioning to be excluded as explanations. Hence, many claims for insight learning depend upon ambiguous criteria, and we still rely upon verbal arguments rather than solid methodology. But we would like to end by stating that the use of shaping during experiments does not exclude insight in animals. But, due to the difficulty of defining exactly how to separate between the two processes, we also want to point out that there might not be a clear-cut boundary between insight learning and shaping.

For a better understanding of animal learning, we need to replace verbal arguments with a formal understanding and a quantitative framework to evaluate both the complexity of a problem, animal behavior, and individual backgrounds.

Cross-References

► Intelligence, Learning, and Neural Plasticity
► Köhler, Wolfgang
► Latent Learning
► Operant Behavior
► Shaping of New Responses
► Tolman, Edward

References

Tolman, E. C., & Honzik, C. H. (1930). Insight in rats. *University of California, Publications in Psychology, 4*, 215–232.

Further Reading

Epstein, R., Kirshnit, C. E., Lanza, R. P., & Rubin, L. C. (1984). 'Insight' in the pigeon: Antecedents and determinants of an intelligent performance. *Nature, 308*, 61–62.

Köhler, W. (1925). *The mentality of apes*. London: Routledge and Kegan Paul.

Pearce, J. M. (2008). *Animal learning and cognition*. Hove: Psychology Press.

Thorpe, W. H. (1964). *Learning and instinct in animals*. London: Methuen.

Tomasello, M., & Call, J. (1997). *Primate cognition*. New York: Oxford University Press.

Insightful Behavior

► Insight Learning and Shaping

Inspiration

► Creativity and Its Nature
► Incentives and Student Learning

Instance Learning

► Rapid Response Learning in Amnesia

Instance-Based Learning

► Episodic Learning

Instance-Learning

► Exemplar Learning and Schematization in Language Development

Instantaneous Transfer

Use of previously acquired spatial information within a novel environment.

Instantiation

Instantiation of a schema or concept corresponds with a specific event or object in reality that fits the content of a schema or a concept.

Instinctive Cueing

► "Clever Hans": Involuntary and Unconscious Cueing

Instructional Agents

► Pedagogical Agents

Instructional Design

► Choreographies of School Learning
► Design of Learning Environments

Instructional Explanations

► Explanatory Support for Learning

Instructional Help

► Situated Prompts in Authentic Learning Environments

Instructional Objectives

► Learning Criteria, Learning Outcomes, and Assessment Criteria
► Learning Objectives
► Outcomes of Learning

Instructional Outcomes

► Alignment of Learning, Teaching, and Assessment

Instructional Planning

► Alignment of Learning, Teaching, and Assessment

Instructional Support

► Collaboration Scripts
► Scaffolding
► Situated Prompts in Authentic Learning Environments

Instructional Systems Design

► Design of Learning Environments

Instructional Tasks

► Learning Tasks

Instructional Technology

► Design of Learning Environments
► Everyday Learning: Instruction and Technology Designs
► Learning Technology

Instructional Television

► Children's Learning from Television

Instructionism

This concept is based on cognitive learning theories that center on teaching as education performed by a teacher. In the view of instructionism, instruction has to be improved in order to achieve better learning results.

Instructions to Forget

► Directed Forgetting

Instrumental Behavior

► Operant Behavior

Instrumental Behavior, Problem-Solving, and Tool Use in Nonhuman Animals

Dorothy Fragaszy, Qing Liu
Behavioral and Brain Sciences Program, Psychology Department, University of Georgia, Athens, GA, USA

Synonyms

Goal-directed action; Means/ends behavior

Definition

Instrumental behavior is action performed to reach a goal, such as to obtain a food item, achieve some other kind of reward, or remove a punishment; the behavior causes the desired outcome. Problem-solving is a subset of instrumental behavior, invoked when a direct action (such as reaching for an object) cannot achieve the goal and an indirect approach must be used (such as opening a container to get the object). To paraphrase Thorndike, a problem exists when the goal that is sought is not directly attainable by the performance of a simple act available in the animal's repertoire. Instead, the solution calls for either a novel action or a new integration of available actions (Scheerer 1963, reprinted in Riopelle 1967). Tool use is a special kind of problem-solving involving use of an object in the problem-solving sequence. An individual uses a tool when it produces a spatial relation between the tool object and the target surface or object, and then uses the tool to alter the target via a dynamic mechanical interaction. As Beck (1980, p. 133) noted, “tool use, in terms of topography, function, [and] causal dynamics, dovetails imperceptibly with other categories of behavior.” It is not a distinct behavioral category recognized by ethologists and physiologists such as “feeding” or “locomotion.”

Theoretical Background

There is no discrete theory of problem-solving. Instead, problem-solving is seen, now and historically, as one dimension of the larger topic of cognition (including learning). Problem-solving is a specially recognized dimension of cognition on account of its dependence on the generation of novel (or at least, less common) behaviors. This feature affords opportunities to study aspects of cognition that are not tapped in highly structured experimental settings, but it requires particular experimental arrangements that permit nonhuman animals to produce varied behaviors, and measurement of behaviors prior to solution (rather than simply choice or latency to perform a certain behavior). Theories of cognitive development, learning, reasoning, self-regulation, and embodied cognition have all been explored using problem-solving paradigms with nonhuman animals.

Important Scientific Research and Open Questions

Natural historians from antiquity through the nineteenth century interpreted problem-solving by animals as evidence of intelligence, and they used anecdotes of individual animals’ impressive performances as evidence of high intelligence. At the turn of the twentieth century, E. Thorndike aimed to establish psychology as a science, and to that end, he proposed that psychologists measure behavior, rather than states of consciousness, the predominant theme in psychology in his era. He considered learning to be critical to the biology of animals, including humans. In keeping with his aim to make psychology an experimental science, and make it relevant to understanding human and animal behavior, he developed an experimental method to examine learning in animals, and he used the context of problem-solving to study learning in diverse species of animals. In his best-known study, he put cats in boxes from which they could escape with simple actions such as pulling a string to open a door. He found that the cats did many irrelevant behaviors but that they eventually (accidentally, the first time) pulled the string and escaped from the box, and they did so more quickly with continued experience being put into the box. He concluded that animals, including humans, could learn by associating discrete behaviors (“trials”) with outcomes (at first, mostly “errors”); i.e., through ► associative learning, also called “trial and error learning,” and that learning could be measured rigorously by the change in time that it took an individual to reach a solution. Thorndike’s pioneering work led to the empirical study of learning in nonhuman animals pursued vigorously, especially in North America, to the present day. However, in Thorndike’s experiments, the subject had no means to perceive the physical relation between elements of the problem (e.g., for the experiments with cats, the string ran outside the box to the catch on the trap door); the cat could not see the string. This led to the criticism that Thorndike’s method could only lead to the subject attempting to escape by performing general, species-typical actions, such as scratching at the wall of the box.

Almost contemporaneously with Thorndike, W. Köhler (an important theorist from the Gestalt school of psychology) proposed a very different model of problem-solving. He was particularly interested in exploring mental continuity between humans and apes, and he suggested that nonhuman animals, like humans, could solve problems using “► insight” (i.e., sudden comprehension derived from an integrated, holistic perception of the relevant parameters of the problem). He conducted experimental studies with captive chimpanzees using what he considered ► naturalistic problems (obtaining food that was visible but out of reach). He provided the apes with materials, all in view, sufficient to solve the problem if used in an appropriate way (e.g., boxes to stack or sticks to use as rakes), and noted the sequence of behaviors the animals performed as well as how long it took them to get the food (or their failure to solve the problem). These studies are widely cited even today. Köhler concluded that chimpanzees could, under the right circumstances, solve problems insightfully (evident in deliberate behavior to reach solution with few or no prior attempts with the relevant materials) rather than through association of randomly generated behaviors with success. It is noteworthy that the problems he presented involved using one or more objects in the service of retrieving another – i.e., the use of tools. The use of tools to study problem-solving remains popular today, as indeed, does the use of “insight” as an explanatory concept. However, use of “insight” as an explanatory concept was at the time Köhler wrote, and remains, controversial (e.g., see Chance 1960, reprinted in Riopelle 1967).

In recent decades, developmental psychological theories, especially Piagetian theory, have been used to explore cognition in nonhuman animals. The aim of these studies is to evaluate the nature of reasoning in animals, as evident in the manner in which problems are approached. Sample experimental problems drawn from Piagetian models and presented to nonhuman animals include seriating cups, pulling in objects placed on continuous versus discontinuous supports, and retrieving objects several times from one location and then from another location (known by the error it produces, “A-not-B,” and by the concept Piaget proposed that it illustrated, “object permanence”). This work has shown that diverse species solve problems which, according to Piaget, require capacities that human infants develop over the first several years of life (relational reasoning, memory of sequences, and representations of absent objects, past events, and future actions). As other theories of development or of action have appeared, so too have studies of animal problem-solving expanded. For example, some researchers have adopted an ecological approach, drawn from J. J. Gibson, to examine the interaction of species-typical behavioral patterns and perceptual biases and the demands of the task in organizing an individual’s approach to a problem. This approach lends itself to explaining taxonomic differences in problem-solving behavior in terms other than “differences in intelligence.” For example, individuals of species that rely on audition to locate food are unlikely to use a stick to search for food.

Much fruitful work in problem-solving has been inspired by the natural behavior of animals. Detouring (moving toward a goal around a barrier) falls into this category. In the first half of the twentieth century, as the experimental paradigms pioneered by Thorndike in studies of animal learning began to take hold, E. Tolman studied rats traveling in mazes. In some experiments, he altered the configuration of alleys after the rat had learned the most efficient route to the goal location, to demonstrate that it could use remembered spatial information (a “cognitive map”) when it needed to detour. ► Detour problems remain popular today to study problem-solving, and are presented along a scale of space, from traditional locomotor problems to two-dimensional computer interfaces presented on a monitor (Brown and Cook 2006).

String-pulling, pulling up a piece of food suspended on a string, is a form of problem-solving observed in wild birds and then adapted for experimental study of birds and other animals. Birds can retrieve food suspended on a string by alternately pulling up the string with the beak and then stepping on the string; mammals retrieve the food by using the mouth and paws or hands to pull in the string. Although some have interpreted this behavior as insightful problem-solving, recent work suggests alternative explanations based on associative learning principles (Taylor et al. 2010).

Interest in tool use by nonhuman animals increased in the middle of the twentieth century, after J. Goodall’s electrifying report of termite fishing by wild chimpanzees. Her report highlighted that manufacturing and using tools in apparently flexible ways was not uniquely human. Reports of tool use by diverse species followed in abundance. Indeed, in a landmark book published 20 years after Goodall’s first observations of tool use in chimpanzees, B. Beck (1980) reviewed reports on tool use and tool manufacture behaviors in a wide range of animal species, including invertebrates, fish, amphibians, reptiles, birds, non-primate mammals, and nonhuman primates. New reports of spontaneous tool use in diverse species continue to appear. The manufacture and use of tools by wild New Caledonian crows to extract invertebrate prey from tree trunks is an especially interesting phenomenon described recently, along with diverse stone and stick tools used by wild capuchin monkeys (see Fig. 1) and long-tailed macaque monkeys. Experimental studies of tool use, some following designs first used by Köhler decades earlier, have also flourished. Well-known examples involve using sticks to push objects out of tubes and rakes to pull in food placed out of reach and around a hole or barrier. New frontiers in this area include studies of brain activity while a tool is used and how skill is manifest in action.

Instrumental Behavior, Problem-Solving, and Tool Use in Nonhuman Animals. Fig. 1 A wild adult bearded capuchin monkey (Cebus libidinosus) using a stone hammer to crack a palm nut (visible between his feet) which he has placed on a stone anvil surface. Two juveniles look on. Photo by Barth Wright, courtesy of EthoCebus.org.

However, as for problem-solving more generally, we have no specific theories of tool use. Instead, researchers study tool use from widely varying theoretical perspectives (Wasserman and Zentall 2006). For example, from a cognitive perspective, researchers want to know how individuals learn to relate objects and actions to achieve a goal, and what they understand of the causal relations involved. From a comparative evolutionary perspective, researchers study tool use in animals to understand precursors of human technology, to identify potentially traditional variations in behavior, and to correlate brain morphology with tool use. From an ecological perspective, researchers are interested in the contribution of tool use to an individual's fitness through access to otherwise inaccessible resources, and the relation between tool use and resources in the environment.

Cross-References

► Köhler, Wolfgang
► Piaget, Jean
► Play, Exploration, and Learning
► Problem Solving
► Schema-Based Problem Solving
► Spatial Cognition in Action
► Thorndike, Edward L.
► Tolman, Edward C.

References

Beck, B. (1980). *Animal tool behavior: The use and manufacture of tools by animals.* New York: Taylor and Francis.

Brown, M., & Cook, R. G. (2006). Animal spatial cognition. Comparative, neural and computational approaches. [On-line]. www.pigeon.psy.tufts.edu/asc/

Riopelle, A. (Ed.). (1967). *Animal problem-solving.* Baltimore: Penguin Books.

Taylor, A. H., Medina, F. S., Holzhaider, J. C., Hearne, L. J., Hunt, G. R., & Gray, R. D. (2010). An investigation into the cognition behind spontaneous string pulling in New Caledonian crows. *PLoS ONE, 5*(2), e9345. doi:10.1371/journal.pone.0009345.

Wasserman, E., & Zentall, T. (Eds.). (2006). *Comparative cognition.* Oxford: Oxford University Press.

Instrumental Conditioning

► Operant Learning

Instrumental Ensembles

► Instrumental Learning in Music Education

Instrumental Learning

► Operant Learning

Instrumental Learning in Music Education

C. Victor Fung[1], Timothy J. Groulx[2]
[1]Center for Music Education Research, School of Music, MUS 101, College of The Arts, University of South Florida, Tampa, FL, USA
[2]Department of Music, University of Evansville, Evansville, IN, USA

Synonyms

Bands; Instrumental ensembles; Instrumental music; Instrumental music education; Orchestras

Definition

Instrumental learning in music education refers to any musical learning situation in which musical instruments are the primary medium of music making. However, vocal exercises may be used as a tool to improve instrumental learning. Instrumental learning in music education includes one-on-one instruction, small-group instruction, or large-group instruction, which may include as many as hundreds of students in an ensemble, such as a marching band in the United States. Instrumental learning may take place in or outside of school. Common Western instruments taught include keyboard instruments, such as piano, accordion, or organ; strings, such as violin, viola, cello, string bass, guitar, and harp; wind instruments, such as recorder, flute, clarinet, saxophone, oboe, bassoon, trumpet, horn, trombone, euphonium, and tuba; and percussion instruments, such as snare drum, drum set, xylophone, timpani, and numerous other percussion instruments. Learners may find teachers who instruct on instruments of various cultural origins, such as the Indian *tabla* or *sitar*, Scottish bagpipes, Caribbean steel drums, West African *djembe*, or Japanese *koto*.

Theoretical Background

The learning of musical instruments has long been an important component in education. The ancient Greeks included the learning of the lyre and the ancient Chinese included the learning of the *qin* to educate the elites of the society. The practice of these musical instruments was believed to exert positive impacts on personal developments, including good morale, high ethical value, and increased understanding of the world. As various institutions were set up to teach musical instruments, some instrumental learning took place within these institutions, while others remain as folk traditions. There were incidences, where musical instruments were banned due to its negatively constructed meanings to the music they produced. For example, musical instruments were banned in many European churches during the medieval period due to their evil connotations then.

Throughout the last millennium, a huge array of musical instruments has been invented or developed. Existing instruments, such as the flute, the trumpet, and various drums, were improved dramatically. New instruments were invented, such as the saxophone, patented in France in 1846, and about a century later, the steel pans in Trinidad. Techniques of producing musical instruments were significantly improved, making mass production a reality. More people were able to have access to musical instruments. At the same time, the music became more complex and could be more technically demanding. The status of instrumental music has been elevated. Instrumental music gained its identity independent to that of vocal music. Musical instruments were not only used to accompany singing. There were rapidly growing repertoires of instrumental music. The learning of musical instruments became more demanding and systematic.

Although music might be part of school education prior to the twentieth century, vocal music seemed to have dominated, in countries such as China and the United States. Instrumental learning was mainly found in private homes, especially keyboard instruments, and other instruments were starting to enter some schools. In the community, military and civic bands in the United States had become popular forms of entertainment from the 1860s through the turn of the century and may have helped to build interest in instrumental music. Bands such as those under the direction of John Philip Sousa, Patrick Gilmore, and Giuseppe Creatore would often travel by railroad and perform programs of music which often consisted of relatively light or popular music. With the advent of the automobile in the early twentieth century, people were no longer reliant upon entertainment coming to them (usually by rail) and the interest in civic bands diminished somewhat, and as a result of "talking pictures," theater musicians and orchestras which had accompanied silent movies became unemployed around this same time (Hansen 2005). This large number of unemployed theater musicians and military musicians returning from World War I helped form the first generation of school-band directors. Musical instrument manufacturers began marketing instruments toward schools and youth organizations such as Boy Scouts and Kiwanis International. These helped instrumental music learning in school settings blossom after World War I (Mark and Gary 2007). Instruments being taught in the schools were mostly Western band and orchestral instruments. They were also taught by other Western musicians, including those from Europe, for example, in the first music conservatory established in China in 1927. Western musical instruments spread quickly throughout China and most parts of the world in educational institutions of all levels. Even in the twenty-first century, this is particularly evident in most of Africa, where Western instrumental learning is mainly found in educational institutions, and the learning of indigenous traditional instruments is pervasive in the community.

In the United States, instrumental learning in school settings has earned a world reputation by the second half of the twentieth century. Bands and orchestras were found in most secondary schools and universities. Specific types of bands became mature forms, including concert band, jazz band, and marching band. The development of the wind ensemble was recognized by musicians across the world. For example, bands in Japan were heavily influenced by bands in the United States (Groulx 2009). Orchestras were also commonplace in schools across Europe and North America, along with the prosperity of professional orchestras in all major cities in these two continents and in many parts of the globe.

While instrumental music learning took place in educational institutions, private one-on-one instruction continued outside of the schools on all types of musical instruments. The method of instruction varied depending on the instrument and the instructor's philosophy. A notable instructional approach for instrumental learning came from Japan, by Shinichi Suzuki (1898–1998). The Suzuki approach, also called "Talent Education" or "Mother-Tongue Method," was originally designed for the violin, but it has been adapted to teaching many other instruments, such as the piano, the flute, and the recorder. The approach was based on Suzuki's theories of language acquisition and the importance of learning from the environment. It emphasized playing the instrument from a very young age, often with a parent also involved in learning at the earliest stages so they could help and motivate the child, and nurturing the child in a musical community with frequent performances. It heavily relied on learning by ear during the early years (Suzuki 1983). There were also many method series for individual or group learning across different instruments, mainly band instruments, such as the *Rubank* series, the *A Tune A Day* series, and the *Jump Right In* series. Each of these series was based on a different philosophy about how one should progress in learning the instruments. Furthermore, the *Teaching Music Through Performance* series published by GIA included graded curricular models and assessment for band, orchestra, and jazz groups.

Systematic assessment of achievement has been an important aspect of instrumental learning in many countries. This is mainly due to the spread of an examination scheme led by the Associated Board of the Royal Schools of Music (ABRSM) and the Trinity College London (TCL), both began in the United Kingdom in the late nineteenth century. The scheme contains a series of graded syllabi for a wide range of musical instruments. Learners are assessed one-on-one. Assessment results are intended to motivate and to encourage learners. Other similar examinations are organized by institutions such as the Australian Music Examinations Board in Australia, the Royal Conservatory of Music in Canada, the Directorate Music of the University of South Africa in South Africa, the Shanghai Conservatory of Music in China, and the Central Conservatory of Music in China. Regardless, ABRSM and TCL have the most extensive offerings of examinations and the most widespread external examination centers throughout the world.

Different musical traditions have different structures for individual instrumental learning. In the Western musical tradition, the timeframe of each instrumental lesson is usually highly structured and preplanned (e.g., weekly 30-min lessons). The focus of the lesson is mostly, if not solely, on the learning of the music and the instrument. In some world musical traditions, individual instrumental learning could be integrated into the lives of both the master teacher and the learner. Learners not only learn the music, they also learn how to live like the master teacher. Learners may live very close to the master teacher. Instrumental learning may take place in a much less defined timeframe and beyond oral-aural learning. Learners learn a way of life with music being part of it. In India, this tradition is called *guru-shishya*; in Japan, it is the *sensei* system. This approach is more common in Asian musical traditions.

In the twenty-first century, instrumental learning may come in all conceivable varieties, sizes, and contexts. The learning of the Western band and orchestra traditions continued mostly in schools and some in the communities. Some schools also offered less common classes, such as guitar, keyboard, steel pans, mariachi, African drumming, and so on. Instrumental learning outside of school was often characterized as informal, which may include rock bands, usually consisting of guitars (including bass guitar), drum set, and keyboards, and other smaller groups, who may be self-taught, especially through imitation of existing popular music. With the advent of technology, some considered the computer or a similar device as a musical instrument. Using the Internet, many more were able to learn musical instruments and to make music as a group at a distance.

Since the second half of the twentieth century, there was a sprawl of professional organizations dedicated to instrumental learning. In the United States alone, such organizations included the American Bandmasters Association, American School Band Directors Association, American String Teachers Association, College Band Directors National Association, and Music Teachers National Association. If technology is treated as a musical instrument, there is also the Association for Technology in Music Instruction.

Important Scientific Research and Open Questions

Scientific research in instrumental learning parallels those of the broader music learning and relevant areas, such as social psychology of music instruction and learning. For example, sex-stereotyping of musical instrument selection, family influence, and musical identity are topics within the purview of social psychology. These areas of research also played an important role in the development of instrumental learning. Other topics that may interest researchers include reasons of dropping out from instrumental music programs, small versus large musical ensemble experiences, the role of vocalization in instrumental learning, and development of sight-reading skills (Weerts 1992).

Although instrumental learning in music education has a long history, there have always been open questions of the time. One such current question is the place of instrumental music in the schools. For example, bands secured a place in American schools in the early twentieth century following a time of immense popularity in the public. After 100 years of school bands participating at high-school football games, concerts, and public parades, some ask the question: How are bands relevant in today's society?

There seems to be a dividing line between instrumental learning in school settings and instrumental learning outside of schools. This division is mainly drawn by musical styles (classical style in school, and popular and folk styles outside of school) and the type of musical instruments used (Western instruments in school, and other instruments, including electronic instruments and folk instruments, outside of school). Is there a way to bring all types of instruments and musical styles to unity within an educational framework? Given the fact that it is not possible to learn about all types of music and instruments, what principles should one use to determine which musical instrument and which musical tradition to learn within an educational institution?

As the society is becoming more health-conscious, a new question arises in how instrumental music learners could prevent health issues related to the instruments they play. Health concerns for instrumental music learners include hearing loss, performance anxiety, and a range of biomechanical problems depending on the instrument involved (Chesky et al. 2002). Regardless of what the answers are for these questions, instrumental music learning is going to continue to prosper based on the needs and contexts of contemporary societies, fulfilling an important need of all humans.

Cross-References

- ► Cognitive Psychology of Music Learning
- ► Developmental Psychology of Music
- ► International Perspectives in Music Instruction and Learning
- ► Multicultural Issues in Music Instruction and Learning
- ► Music and Learning
- ► Music Instructional Methods
- ► Social Psychology of Music Instruction and Learning
- ► Technology in Music Instruction and Learning

References

Chesky, K., Kondraske, G., Menoch, M., Hipple, J., & Rubin, B. (2002). Musicians' health. In R. Colwell & C. Richardson (Eds.), *The new handbook of research on music teaching and learning* (pp. 1023–1039). New York: Oxford University Press.

Groulx, T. (2009). American influences on Japanese bands. *Music Education Research International, 3*, 1–12.

Hansen, R. K. (2005). *The American wind band: A cultural history.* Chicago: GIA.

Mark, M. L., & Gary, C. L. (2007). *A history of America music education* (3rd ed.). Lanham: Rowman & Littlefield Education.

Suzuki, S. (1983). *Nurtured by love: The classic approach to talent education.* 2nd ed: (trans: Suzuki, W.). Smithtown: Exposition Press.

Weerts, R. (1992). Research on the teaching of instrumental music. In R. Colwell (Ed.), *Handbook of research on music teaching and learning* (pp. 577–583). New York: Schirmer Books.

Instrumental Music

► Instrumental Learning in Music Education

Instrumental Music Education

► Instrumental Learning in Music Education

Instrumentation

► Tool Use and Problem Solving in Animals

Intact Implicit Learning in Autism

Jamie Brown
Department of Experimental Psychology, University of Cambridge, Cambridge, UK

Synonyms

Preserved implicit learning in autism; Unimpaired implicit learning in autism

Definition

Intact implicit learning in autism refers to the assertion that individuals with autism perform equivalently to individuals without autism on a range of implicit learning tasks.

Theoretical Background

Implicit learning is popularly defined as learning that proceeds unconsciously, although this conception is strongly contested. There is better evidence and consensus for another definition: Learning is implicit when the learner is not primarily engaged in trying to learn, and is consequently unable to report verbally on how or what was learnt. Such learning is believed to be one important mechanism for acquiring social, communicative, and motor skills. Since autism is characterized by social, communicative, and motor impairment, several researchers have theorized that there may be a general implicit learning deficit in autism (e.g., Klinger et al. 2007; Mostofsky et al. 2000). In order to test this theory, researchers investigated whether performances on implicit learning tasks were impaired or intact in autism.

Important Scientific Research and Open Questions

The theory that impaired implicit learning plays a role in autistic symptomatology is largely unsupported by the evidence. Five different studies have now compared autistic individuals with matched controls on implicit learning tasks without finding differences in overall performance (Barnes et al. 2008; Brown et al. 2010; Kourkoulou et al. in press; Nemeth et al. 2010; Travers et al. 2010). In one of these studies, which compared the same individuals on four different implicit learning tasks, there was an additional analysis that demonstrated the implicit learning performances of individuals with and without autism were statistically equivalent (Brown et al. 2010).

It should be noted that some earlier studies reported implicit learning deficits in autism (e.g., Klinger et al. 2007; Mostofsky et al. 2000). However, authors have argued that those deficits resulted from differences in methodology (Brown et al. 2010; Nemeth et al. 2010). In particular, it has been suggested that earlier studies used procedures that encouraged explicit strategies, which disadvantaged the autism groups because they had not been matched for IQ. IQ is closely related to explicit, but not implicit, learning. Brown and colleagues (2010) found support for this interpretation when conducting a further analysis that compared autistic individuals with controls who were not matched for IQ: The autism group exhibited a deficit on an explicit learning task, but remained equivalent on the implicit learning tasks.

The finding that implicit learning is intact in autism might appear incongruous with the profound and diagnostic difficulties that autistic individuals have with "implicit" skills in everyday life, such as social, communicative, and motor behaviors. However, this apparent incongruity is reconciled by the fact that intact implicit learning is necessary to the implicit acquisition of real-world skills but it is not sufficient. A number of established autistic differences in other distinct processes are likely to be relevant: Unusual attentional biases or the overuse of atypical explicit strategies could interfere with learning in certain contexts; difficulties with the application of implicitly acquired knowledge could prevent the expression of learning; and sleep difficulties could cause atypical consolidation following learning. Relevant to this latter possibility, one recent study reported that the consolidation of implicit learning across 16 h (including a night of sleep) was actually intact in autism (Németh et al. 2010). Future research in the area is likely to focus on establishing exactly which, and how, processes that differ in autism are relevant to the disruption of otherwise intact implicit learning mechanisms during the acquisition of communicative, social, and motor skills.

Cross-References

- ▶ Attention and Implicit Learning
- ▶ Explicit Versus Implicit Learning
- ▶ Implicit Attentional Learning
- ▶ Implicit Sequence Learning
- ▶ Incidental Learning
- ▶ Learning in Autism

References

Barnes, K. A., Howard, J. H., Jr., Howard, D. V., Gilotty, L., Kenworthy, L., Gaillard, W. D., et al. (2008). Intact implicit learning of spatial context and temporal sequences in childhood autism spectrum disorder. *Neuropsychology, 22*(5), 563–570.

Brown, J., Aczel, B., Kaufman, S. B., Jiménez, L., & Plaisted Grant, K. C. (2010). Intact implicit learning in autism spectrum conditions. *The Quarterly Journal of Experimental Psychology, 63*(9), 1789–1812.

Klinger, L. G., Klinger, M. R., & Pohlig, R. (2007). Implicit learning impairments in autism spectrum disorders: Implications for treatment. In J. M. Pérez, P. M. González, M. L. Comí, & C. Nieto (Eds.), *New developments in autism: The future is today* (pp. 76–103). London: Jessica Kingsley.

Kourkoulou, A., Leekam, S., & Findlay, J. (in press). Implicit learning of local context in autism spectrum disorder. *Journal of Autism and Developmental Disorders.*

Mostofsky, S. H., Goldberg, M. C., Landa, R. J., & Denckla, M. B. (2000). Evidence for a deficit in procedural learning in children and adolescents with autism: Implications for cerebellar contribution. *Journal of the International Neuropsychological Society, 6*(7), 752–759.

Nemeth, D., Janacsek, K., Balogh, V., Londe, Z., Mingesz, R., et al. (2010). Learning in autism: Implicitly superb. *PLoS ONE, 5*(7), e11731.

Travers, B. G., Klinger, M. R., Mussey, J. L., & Klinger, L. G. (2010). Motor-linked implicit learning in persons with autism spectrum disorders. *Autism Research, 3*(2), 68–77.

Integrated Architectures

This theoretical term is widely used in the field of machine learning and refers to "multistrategy" learning. Although there is no agreement on what "integration" exactly means in Machine Learning, integrated architectures are defined as architectures which are organized or structured in such a way that its constituents function cooperatively.

I

Integrated Learning Systems

Stefanie Lindstaedt[1], Claudia Thurner-Scheuerer[2]
[1]Division Manager Knowledge Services, Know-Center & Knowledge Management Institute, Graz University of Technology, Graz, Austria
[2]Knowledge Services, Know-Center & Platform Knowledge Management (Plattform Wissensmanagement), Graz, Austria

Synonyms

e-Learning; Learning content management system(s); Learning management system(s); Work-integrated learning system(s)

Definition

The term Integrated Learning Systems was an early attempt to denote learning systems which incorporate a large variety of functionalities involved in the management of courses, students, administration of grades, delivery of learning content, etc. Over the years, three terms have emerged which are used to reference three different types of learning support systems, namely: Learning Management Systems, Learning Content Management Systems, and Work-Integrated Learning Systems. To start with, a short overview describes the three types of systems.

- *Learning Management System(s) (LMSs)*

  The origin of Learning Management (LMSs) is grounded in the educational and research area. LMSs are widely recognized as computational solutions designed to manage courses, deliver predefined instructional content to the learner, and administer exams. Originally, LMSs were developed in the field of classroom education, where these computer-based instructional systems served as both instructional medium and management information system. One advantage of LMSs is the opportunity to offer courses appropriate for different backgrounds of the learners and monitor individual learner performance (through administering exercises or tests).
- *Learning Content Management System(s) (LCMSs)*

  While a LMS caters to the needs of the learners and the administrators, a Learning Content Management System (LCMS) is designed to support the work of teachers and instructors when creating new learning content. In that it is a workflow system which focused on the development, management, and publishing of the content that will typically be delivered via an LMS. A LCMS is a multiuser environment, where developers manage the process of creating; editing; storing; and delivering e-learning content, ILT materials, and other training support deliverables. One of the main goals with LCMSs is to avoid redundancy and contradictory information.
- *Work-Integrated Learning System(s) (WILSs)*

  Both LMSs and LCMSs are established types of learning systems for which a multitude of commercial products exist. WILSs on the other hand are a new type of learning support which focuses on overcoming the separation of learning and working by supporting learning *integrated* within work activities. Since this kind of learning support is still in the research state, no commercial products are available yet (only research prototypes). For these systems, the terms Integrated Learning Systems or Work-Integrated Learning Systems have been employed lately. This article focuses primarily on WILSs.

  Work-integrated learning is truly integrated into current work processes and practices and makes use of existing (learning) resources within an organization (e.g., project documentation, notes, mails, etc.). From a learner's perspective, workplace learning is spontaneous and/or unintentional and mostly self-directed, meaning that the learner is empowered to take responsibility for their own learning activities. Therefore, WILSs are highly interactive. The main goals of WILSs are to enable and to motivate employees to perform work of higher quality and to learn continuously during work, resulting in increased productivity.

Theoretical Background

LMSs today are used heavily within the educational domain (schools or higher education) which provided students with learning experiences. The system manages the delivery of curriculum materials (electronic courses) to individual learners and is capable of providing comprehensive feedback to the learner and the teacher (Fitzgerald and Fitzgerald 2002). Computer use in classrooms as an aid to the teaching and learning process has become very popular over the past 2 decades. Educational organizations have seen a wide introduction of computers and other types of instructional technologies into classrooms (as cited in Mazyck 2002). In addition, LMSs are used extensively in large corporations which need to educate their employees in a timely manner on new products, processes, and guidelines. In all cases, LMSs and LCMSs are mainly employed from the organizational point of view in order to help the organization to manage the creation of the content, its delivery, the courses, grades, etc. One difference between traditional LMSs solutions and WILSs is that in the first case, learners are sent to the "learning," while in the second case, the "learning" is brought to the learners' working environment. This allows work-integrated learning to better cope with the gap between individual demands of a learner and the demands of an organization (Tochtermann and Granitzer 2008). The main goal is to enable and to motivate more employees to do more knowledge work of a higher quality and to learn continuously during work.

The practice of one-on-one or one-on-few teaching was abandoned for the sake of mass education and led to the rather artificial separation of working and learning for the sake of work efficiency. Later on, computational systems were designed with the goal to support either the one or the other. Workflow management, performance support, and knowledge management systems evolved in the quest for supporting (specific) work processes. On the other side, tutoring and e-learning systems evolved to help people learn more efficiently. And while there now is growing understanding in the research communities that integration of knowledge management (organizational learning) and e-learning is desirable and necessary, the approaches are still in their infancy and primarily focus on the integration on the system level. For example, e-learning systems are increasingly used at the workplace, and courses are offered in smaller granular modules. Another example is that lesson learned descriptions are used to train people within the organization.

The implementation of WIL within an organization faces three challenges: real-time learning, real knowledge resources, and real computational environment (Lindstaedt et al. 2010).

1. *Real-time learning:* WIL support should make knowledge workers aware of and support them throughout learning opportunities relevant to her current work task. WIL support needs to be adapted to a user's work context and her experiences, and should be short and easy to apply.
2. *Real knowledge resources:* WIL support should dynamically provide and make users aware of available knowledge resources (both human as well as material) within the organization. By providing "real" resources, the effort for learning transfer is reduced and the likelihood for offering opportunities to learn on different trajectories is increased.
3. *Real computational environment:* WIL support should be provided through a variety of tools and services which are integrated seamlessly within the user's desktop and allow one-point access to relevant back-end systems of her organization. These tools and services need to be inconspicuous, tightly integrated, and easy to use. They must support the knowledge worker in effortlessly switching between varieties of learning practices.

So meeting the challenges, a WIL concept helps knowledge workers to move fluidly along the whole spectrum of WIL activities. By doing so, knowledge workers experience varying degrees of learning guidance: from building awareness, overexposing knowledge structures, and contextualizing cooperation to triggering reflection and systematic competence development. An example of the described WIL support can be found in the prototype developed within the EU project APOSDLE (www.aposdle.org).

A modern theoretical model that fits to the concept of WILS can be found at Kelloway and Barling (2000). Based on the research of Kelloway and Barling knowledge, workers are free to choose whether or not and to which extent they are willing to invest their abilities for the sake of the company. This new understanding of knowledge work puts the focus on work-integrated learning as a crucial part of and inseparably intertwined with knowledge work. In this, learning is an integral part of all identified knowledge work types – create, acquire, transfer, apply – and, furthermore, learning is both by-product and enabler of knowledge work.

Important Scientific Research and Open Questions

Work-integrated learning is not a new invention, and various studies have shown that knowledge work and work-integrated learning has taken place for centuries. A very close integration of working and learning in which the learning aspects have received considerable attention can be found in the old tradition of apprenticeship learning as studied by Lave and Wenger (1991). Kelloway and Barling (2000) in their in-depth analysis and critique of approaches to define knowledge work identified three mediators for successful knowledge work: the ability of the person, her motivation to apply her skills and knowledge, and her opportunity to do so.

In order to improve productivity of knowledge workers, technological support should not limit itself to supporting the immediate knowledge work types (create, acquire, transfer, apply) but should also seek to influence the mediating factors positively. In particular, by specifically supporting learning situations during everyday work (increasing ability), by increasing a person's awareness about challenging learning goals related to the work situation (motivation), and by making tasks and possibilities for learning and collaboration transparent to people (opportunity).

Based on these insights from workplace learning and knowledge work research, work-integrated learning can be described by the following characteristics:

- Individuals are responsible for their own competency development, and they learn autonomously: they set their own learning goals, are responsible for time management and results, and chose their own learning strategy.
- Individuals are enabled to learn within their own specific work processes and context: when a learning situation during work occurs, the individual in general is empowered to satisfy the learning need at that moment (real-time learning).
- Individuals are enabled to learn within their own computational work environment: learners are not forced to switch to other tools for accessing learning material and contacting relevant subject matter experts but are enabled to do so using their familiar tools (real learning environment).
- Individuals are enabled to learn from resources available within their own organizations: learners are made aware of and are supported in learning from resources which were not originally created with the intention of teaching, but which are typical work results (for example, project reports).
- Individuals are enabled to (collaboratively) learn from and with other people within their own organization: learners are made aware of and supported in learning from and with peers and experts.
- Organizations provide the work environment (also including flexibility, time, etc.) to enable this competency advancement and actively support it in their cultures.

It remains to be seen what changes such as the global economy, the scientific information explosion, new educational demands, new collaboration tools at work, mobile devices for knowledge workers or Enterprise 2.0 will have on the trend of using of WILSs in modern education at school- and/or in work-life. Lifelong Learning has already become an essential ingredient for success within nowadays knowledge society.

Cross-References

► Learning-Based Knowledge Representation
► Learning Management System
► Learning Technology
► Technology-Based Learning
► Technology-Enhanced Learning Environments
► Workplace Learning

References

Fitzgerald, D., & Fitzgerald, R. N. (2002). The use of Integrated Learning Systems in developing number and language concepts in primary school children: A longitudinal study of individual differences. Literacy Program Grants for National Strategies. Research Monograph. DEST Clearinghouse: Griffith University. 88 pp. Available from http://www.dest.gov.au/sectors/school_education/publications_resources/profiles/

Kelloway, E. K., & Barling, J. (2000). Work as organizational behaviour. *International Journal of Management Reviews, 2*(3), 287–304.

Lave, J., & Wenger, E. (1991). *Situated learning – legitimate peripheral participation.* Cambridge: Cambridge University Press.

Lindstaedt, S.N., Kump, B., Beham, G., Pammer, V., Ley, T., Dotan, A., & de Hoog, R. (2010). Providing varying degrees of guidance for work-integrated learning. In M. Wolpers, P. A. Kirschner, M. Scheffel, S. Lindstädt, V. Dimitrova (Eds.), *Sustaining TEL: From innovation to learning and practice, Proceedings of EC-TEL 2010.* Springer.

Mazyck, M. (2002). Integrated learning systems and students of color: Two decades of use in K-12 education. *TechTrends, 46*, 33.

Tochtermann, K., & Granitzer, G. (2008). The long way towards workplace-integrated learning. *Proceedings of the 2008 Eighth IEEE International Conference on Advanced Learning Technologies*, IEEE Computer Society.

Further Reading

APOSDLE, http://www.aposdle.tugraz.at/. Accessed 9 Sept 2010.
Becker, J. (1993). A model for improving the performance of integrated learning systems. In G. Bailey (Ed.), *Computer based integrated learning systems*. New Jersey: Educational Technology Publications.
Commonwealth of Australia (2002). Canberra: JS McMillan Printing Group.
Eraut, M., & Hirsh, W. (2007). *The significance of workplace learning for individuals, groups and organisations* (SKOPE Monograph, Vol. 9). Oxford: Oxford University, Department of Economics.

Integrated Learning Theory

► Metatheories of Learning

Integrated, Multidisciplinary, and Technology-Enhanced Science Education

Ivo D. Dinov
UCLA Statistics, University of California Los Angeles,
SOCR Resource, Los Angeles, CA, USA

Synonyms

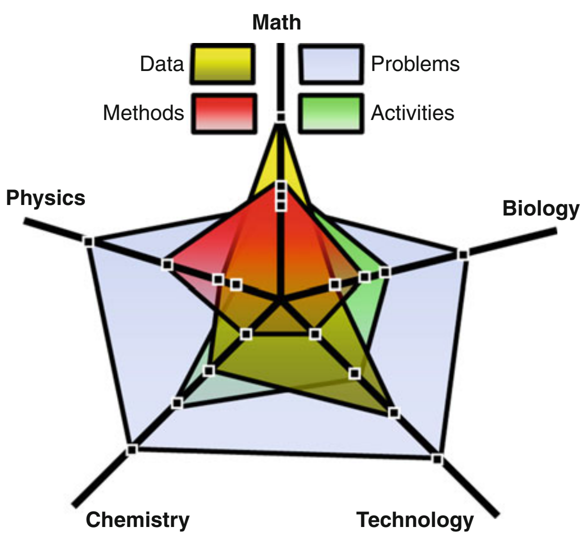
Blended instruction; Broad science education; Cross-disciplinary education; Information and communication technology enhanced education; Interdisciplinary education; Translational education

Definition

Integrated, multidisciplinary, and technology-enhanced science education (Dinov 2008) refers to a holistic science educational approach where motivation, data, theories, techniques, tools, and results from various disciplines are collectively utilized to enhance the pedagogical efforts and improve the learning processes of knowledge acquisition and retention. Multidisciplinary refers to the broad spectrum of scientific fields that are collectively employed to provide heterogeneous training experiences for learners. Technology-enhanced implies that the latest information, communication, and computational technologies are directly embedded in the curricular training. Integrated signifies that this educational approach incorporates modern pedagogical strategies with available technological advancements and novel cross-disciplinary scientific knowledge.

Theoretical Background

There are two symbiotic approaches in general science education. The first one is *advanced and specialized science education* within a specific discipline. Examples include advanced training in one core scientific domain like mathematics, physics, chemistry, and so on. In fact, there are deeper sub-specialization areas that provide innovative high-level training at the cost of further narrowing the scope of the scientific education. In mathematics, for instance, there are advanced scientific training sub-domains like algebraic topology, game theory, spectral analysis, etc. Depending on the learners' interests, instructors' expertise, and the curricular goals, advanced-specialized science education may be introduced in the different levels – middle school, high school, or college.



The second approach to science education involves the *broad core-knowledge training in diverse disciplines* where learners are exposed to basic principles, fundamental applications, and comprehensive interrelations between various scientific areas. Because of its dependence on discipline-specific scientific knowledge, multidisciplinary and technology-enhanced education is typically introduced later in live – college, graduate, or postgraduate curricula. For instance, the area of Neuroinformatics (Koslow and Huerta 1997) is a crossbreed between biology, mathematics, chemistry, statistics, and physics. As most Neuroinformatics developments, studies and applications utilize techniques, approaches, and tools from several different scientific areas, prior training in many these disciplines is critical before a learner is exposed to Neuroinformatics science. The synergy between the advanced-specialized and the broad-multidisciplinary education is rooted in the dichotomy of inductive and deductive knowledge acquisition. The area of health informatics provides a clear example of the integrated nature of the unidisciplinary and multidisciplinary science education where the push–pull interactions between basic science and translational developments provide the basis for advanced applications, productive collaborations, knowledge, and tool sharing (Roberts 2006). Many cross-disciplinary efforts are driven by basic scientific advances in one or several disciplines, and at the same time provide motivation and challenges that push the boundaries of knowledge within individual scientific fields (Stokols et al. 2008).

Metaphorically, education based on advanced scientific training within a specific core discipline can be thought of radial-knowledge, which can be represented as the spokes on a bicycle wheel or the Y-shaped threads on a spider web. On the other hand, multidisciplinary science education can be viewed as space-filling knowledge resembling the circular threads in a spider web. Multidisciplinary and technology-enhanced science education represent the angular or spiral links in the knowledge space, connecting tangential knowledge areas representing different scientific fields radiating outward like discipline-bound spokes. Integrated, multidisciplinary, and technology-enhanced science education enables sharing of driving motivational problems, real data, techniques, and activities between different areas. This process enriches learning experiences, reinforces the importance of discipline-specific knowledge and enables the development and utilization of advanced information, communication, and computation technologies addressing real live problems.

Collectively, the discipline-specific and the multidisciplinary science education encapsulate mankind's complete knowledge of nature, its fundamental laws, and core processes (Brint et al. 2009). The interplay between unidisciplinary and multidisciplinary science education provides the foundation for understanding basic scientific principles, developing new scientific methods, designing novel tools and systems, investigating complex research challenges, and making informed decisions about important social, health, and environmental problems.

Important Scientific Research and Open Questions

Integrated, multidisciplinary, and technology-enhanced science education focuses on synthesizing broad perspectives, integrated knowledge, applied skills, and interconnections between different areas (Klein 1990). This approach facilitates holistic and cohesive scientific studies that may not be adequately understood from a single disciplinary perspective. Supporters of interdisciplinary scientific education argue that discipline-specific training promotes high-level of segmented knowledge. Opponents of multidisciplinary education suggest a lack of synthesis in this training approach, as despite being exposed to multiple disciplinary perspectives, learners may not have sufficiently deep knowledge in any one area, and may lack skills to resolve conflicts or achieve a coherent understanding of a general subject.

The debate over the individual and societal benefits, or detriments, of integrated multidisciplinary science education is fueled by arguments about its realistic values, the interplay between general knowledge and advanced intellectual maturity, and the pragmatic challenges in establishing such training programs. There are also debates on the most efficient mechanisms of broadly educating informed, engaged and proactive citizens, including decision-makers capable of understanding, analyzing, evaluating, and synthesizing heterogeneous information, proposing rational solutions and executing appropriate actions to address ongoing challenges. Perhaps the most critical challenge in implementing multidisciplinary and technology-enhanced education is the requirement for motivated, broadly trained and highly experienced educators. Based on their personal research and application experiences, such instructors must be able to draft appropriate curricula, and at the same time, be capable of delivering this knowledge and training to their specific learning audiences. Established institutional structures, resource limitations, and domain-specific organizational hierarchies may also present significant barriers to developing and implementing integrated multidisciplinary and technology-enhanced scientific curricula. Finally, the timing and format of introducing integrated multidisciplinary and technology-enhanced education to learning audiences remains an open question subject to cultural, social, individual, and geographic factors.

Cross-References

▶ Developmental Cognitive Neuroscience and Learning
▶ History of the Sciences of Learning
▶ Interdisciplinary Learning
▶ Learning Technology
▶ Models and Modeling in Science Learning
▶ Multidisciplinary Learning
▶ Science, Art, and Learning Experiences
▶ Technology-Based Learning
▶ Values in Education and Life-Long Learning

References

Brint, M., Marcey, D., et al. (2009). *What are the long term implications of integration/interdisciplinary science on traditional disciplines and their professional associations (Turf wars)? Integrated science* (pp. 69–76). US: Springer.

Dinov, I. (2008). Integrated multidisciplinary and technology-enhanced science education: The next frontier. *Journal of Online Learning and Teaching, 4*(1), 84–93.

Klein, J. (1990). *Interdisciplinarity: History, theory, and practice.* Detroit: Wayne State University.

Koslow, S., & Huerta, M. (1997). *Neuroinformatics: An overview of the human brain project.* New Jersey: Lawrence Erlbaum Associates.

Roberts, J. (2006). Isolation to interface to integration – is it feasible to seek a holistic profession? *Methods of Information in Medicine, 45*(5), 471–473.

Stokols, D., Hall, K., et al. (2008). The science of team science. *American Journal of Preventive Medicine, 35*, S77–S89.

Integrating Knowledge

▶ Knowledge Integration

Integration Strategies

▶ Elaboration Effects on Learning

Integrative Goals

▶ Complex Learning

Integrative Theory

▶ Motivation, Learning, and Performance

Intellect

▶ Abilities to Learn: Cognitive Abilities
▶ Openness to Experience

Intellectual Curiosity

▶ Epistemic Curiosity

Intellectual Tasks

▶ Cognitive Tasks and Learning

Intelligence and Skill

▶ Ability Determinants of Complex Skill Acquisition

Intelligence, Learning, and Neural Plasticity

Aljoscha C. Neubauer
Department of Psychology, University of Graz, Graz, Austria

Synonyms

Cognitive ability; Neuroplasticity

Definition

Intelligence reflects a general cognitive capability that involves the ability to learn quickly, learn from experience, the ability to reason, solve problems, and understand complex ideas. Individuals are known to differ with respect to this general cognitive ability.

Neural plasticity describes the phenomenon that not only the brain's activity but also the brain's structure can be changed through learning and practice, i.e., the brain is "plastic" or malleable not only during a "critical period" in childhood but also in adulthood.

Theoretical Background

Individual differences in human intelligence have been studied for more than 100 years beginning with Francis Galton's early attempts to study how talent and giftedness runs in families (Hereditary genius, 1869) as well as Binet and Simon's first edition of an "intelligence test" (1905). In the twentieth century, hundreds of empirical studies have shed light on the measurement and structure of human intelligence (cf. entry "► Intelligence and learning"). However, it was not before the late twentieth century that attempts have been made to understand human intelligence from the viewpoint of neuroscience.

The neuroscience approach to individual differences in human intelligence, namely, general cognitive ability, aims at finding correlates of these differences in two aspects of the brain: brain structure and brain function. The first aspect refers to the topography, i.e., regional distribution of the amount of so-called gray matter and white matter. The question thus is whether more intelligent individuals have more neurons, synapses, dendrites (which appear gray in the brain scanner's images), or more myelinated axons (which appear white in the brain scanner) and if these differences are specific to certain areas of the brain, especially the cortex. These structural or anatomical aspects of the brain are measured by means of a "brain scanner," which is typically a magnetic resonance imaging (MRI) device. MRI provides high-resolution topographical pictures of the regional distribution of gray matter and white matter (with MRI only these two broad aspects can be distinguished; in the living brain it is not yet possible to measure directly, e.g., the number of neurons, dendritic connections between neurons, and their connecting synapses).

The second aspect studied in neuroscience approaches to human intelligence focuses on the question which brain areas (mostly areas in the cortex) are activated when individuals work on more complex cognitive problems like solving verbal analogies or continuing number series that follow a certain rule (to name only two out of many different cognitive tasks usually presented in intelligence tests). Brain activation can be measured in different ways. The MRI scanner is also capable of measuring the topographic distribution of blood flow (precisely, the oxygenation of the blood) in all areas of the brain (this is called functional MRI or fMRI).

An alternative method is to measure the electrical activity of the brain by means of either the electroencephalogram (EEG) or the magnetoencephalogram (MEG). These methods involve the mounting of electrodes on the head surface in order to measure the electrical activity or magnetic fields generated by thousands of synapses below the skull surface.

With respect to human intelligence, both aspects have been used to study whether brighter versus less bright individuals differ regarding:

(a) Their brain structure: Do more intelligent individuals have more or less gray matter and white matter and in which parts of the brain?
(b) Their brain function and usage: Do more intelligent individuals show more or less brain activation when working on cognitive problems, and in which areas of the brain?

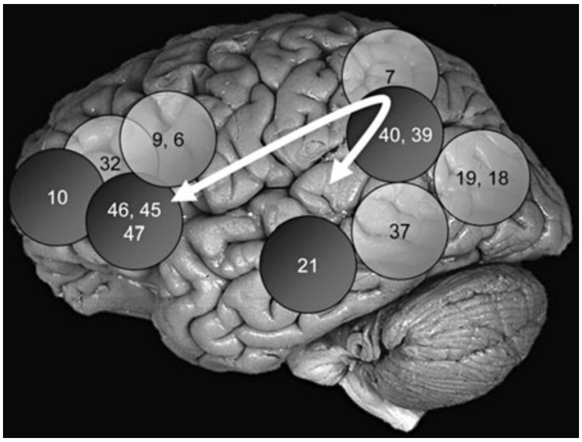
Intelligence is considered to be a rather stable human trait throughout the life span. Moreover, a substantial genetic influence has been found: Behavior genetic research (twin and adoption studies) has shown that the genetic influence accounts for 50–70%, with the remaining percentage due to environmental influences, i.e., learning environments in the broadest sense, like family, friends and peers, kindergarten, school, university, and all other educational as well as professional environments. This on one hand means that there is some genetic predisposition which influences the individual level of general cognitive ability; on the other hand this also means that the (learning) environment can influence the phenotypic (i.e., behavioral) level of human intelligence and that learning influences or efforts especially in childhood and adolescence have an impact on the adult level of cognitive ability.

In the following section, the findings on neuroscience correlates of human intelligence shall be juxtaposed with recent evidence showing that neither brain activation nor brain structure is completely fixed by the genetic disposition but that learning might have a substantial impact on the brain itself, a phenomenon termed "neural plasticity."

Important Scientific Research and Open Questions

Structural Correlates of Intelligence

Studies dealing with the brain's *structural* correlates of intelligence have shown moderate positive relationships (i.e., statistical correlations) between the individual level of intelligence (as determined by reliable and valid intelligence tests) and the amount of gray and white matter (cf. Deary et al. 2010, for a review). This generally means that more intelligent persons possess more neurons, synapses, dendrites, as well as more strongly myelinated (i.e., isolated) axons (the long connections between more distant brain areas). Topographically, a review of pertinent studies has shown that it is mostly some brain areas of the cerebral cortex in which the amount of gray matter correlates with intelligence. In their parieto-frontal integration theory (P-FIT), Jung and Haier (2007) hypothesize that the processing of complex cognitive tasks first requires an input intake into the auditory and visual cortex of the temporal and occipital lobes, then information is passed on to the parietal lobe and the gyrus angularis for processing and abstracting, and at this, the parietal lobe interacts with the frontal lobe via the arcuate fasciculus (see Fig. 1). The prefrontal areas are involved in processes of action planning, decision making. Moreover, and maybe most important for intelligence, they constitute the main network for working memory, which itself is considered to be a significant source of human intelligence differences.



Intelligence, Learning, and Neural Plasticity. Fig. 1 Brain regions by Brodmann area (BA) associated with better performance on measures of intelligence and reasoning that define the P-FIT model. Numbers = BAs; *dark circles* = predominant left hemisphere associations; *light circles* = predominant bilateral associations; *white arrow* = arcuate fasciculus (Reprinted with permission from Jung and Haier (2007))

Functional Correlates of Intelligence

The evidence with respect to brain activation and intelligence is more mixed. The majority of studies measuring brain activation during cognitive task performance showed negative relationships with the level of intelligence (independently assessed by means of intelligence tests), i.e., brighter individuals display *lower* brain activation as compared to less bright individuals (cf. Neubauer and Fink 2009). This finding is usually interpreted in terms of the so-called neural efficiency hypothesis, proposed by Richard Haier et al.: "Intelligence is not a function of how hard the brain works but rather how efficiently it works. . . . This efficiency may derive from the disuse of many brain areas irrelevant for good task performance as well as the more focused use of specific task-relevant areas." (Haier et al. 1992, p. 415). However, as recently shown in a review of the pertinent literature (Neubauer and Fink 2009) there is also contradictory evidence showing that under certain conditions the relationship reverses toward positive correlations, i.e., more intelligent individuals display more brain activation. This is especially true when individuals work on very complex tasks; here obviously brighter persons invest more of their brain resources while less intelligent individuals seem to "regulate down" their brain activation, investigating fewer resources. The reason for this reversal of the neural efficiency phenomenon is currently an open question (see Neubauer and Fink 2009, for a discussion of this issue).

Learning and Neural Plasticity

With respect to these findings on structural and functional correlates of intelligence, the question arises whether brain structure is largely genetically determined, which would therefore also determine the (phenomenological) level of intelligence. This assumption is at odds with more recent evidence from the neurosciences demonstrating that processes of learning might not only change brain activation but that – after longer (i.e., weeks or months-long) domain-specific learning – even changes in brain structure (especially regional gray matter) can be observed (cf. review by Draganski and May 2008). Two kinds of studies have demonstrated this: A first group of studies collected structural brain scans of people with special expertise in certain knowledge domains (e.g., second language, taxi drivers, musicians) and found positive relationships between the amount of regional gray matter and the degree of expertise: The more experience and therefore expertise or knowledge an individual has required in a certain area, the larger are those brain areas that are specialized to perform tasks of a certain domain (e.g., the right posterior hippocampus for navigation skills in taxi drivers). A second group of studies investigated brain scans before and after people were trained or had learnt in some special domain (e.g., juggling, exam in medical students) and observed gray matter increases in specialized areas (e.g., motor brain areas for juggling). This shows that already a training of a few weeks leads to measurable changes in the anatomical structure of the brain, a recent finding that until the late 1990s would have been at odds with the traditional view that learning or practice might change only brain activation but not structure (changes in brain activation with learning/training are well-documented, cf. Kelly and Garavan 2005).

Stable Intelligence Versus Neural Plasticity

The question remains open how this evidence on the "malleability" of the brain relates to the evidence on structural and functional brain correlates of human intelligence differences. How can we speak of a rather stable disposition to be able to solve more complex problems when at the same time our brains seem surprisingly malleable?

At present, this question can be answered best when looking at the few studies on the heritability of the brain structure (for a review see Deary et al. 2010). These twin studies show that the genetic influence on brain structure varies strongly between brain areas, with a quite high genetic determination in the frontal cortex (80–90%) and surprisingly low genetic influence in the more posterior parts of the brain (20–30%), including also the parietal, temporal, and occipital brain areas, that are referred to in Jung and Haier's P-FIT theory (see above). As these brain areas serve quite different functions with respect to cognitive performance, the apparent paradox between the assumptions of a stable trait of intelligence and of the malleability of the brain might be explained. At this, the following assumptions/empirical findings should be considered:

1. The prefrontal cortex subserves mostly the function of working memory, which itself is a key function for a central component of intelligence, i.e., reasoning. The process of reasoning is more important the less an individual can rely on previous knowledge (stored in long-term memory), i.e., when the cognitive task involves novel aspects which require flexible/fluid thinking.
2. The parietal cortex subserves the function of long-term memory, which is of higher importance when the task draws on previous knowledge for solution (e.g., verbal tasks like word fluency tasks).
3. Studies on the effect of learning on brain activation have mostly shown that learning makes the brain more (neurally) efficient, i.e., the better trained a person is in a certain domain the less brain activation he/she needs for coping with the task demands. Moreover, studies have shown that the more a task draws on the acquired knowledge (i.e., expertise) of a person, the less important are individual differences in intelligence. For example, the phenomenon of neural efficiency (i.e., less brain activation in brighter individuals) can be observed rather with novel, untrained tasks (usually like those in intelligence tests; or in real life when people have to acquire new knowledge). For overlearnt tasks (i.e., strongly drawing on the expertise of

individuals), however, a more efficient brain activation is generally found, independent of the individual level of intelligence.

On the basis of these assumptions, we can conclude that the paradox between the assumption of a stable trait of intelligence versus the phenomenon of neural plasticity can be resolved considering the role of task novelty: The more novel a task is, the more important are (rather heritable) functions of working memory, located in the prefrontal cortex, whereas the more a task draws on knowledge and expertise the more important become the (less heritable and, therefore, more malleable) posterior parts of the brain. Intelligence is especially important for dealing with new cognitive tasks (including learning/acquiring new knowledge). The more knowledge in a domain has been acquired (and stored in the malleable posterior parts of the brain), the less important become stable individual differences in human intelligence.

Cross-References

▶ Abilities to Learn: Cognitive Abilities
▶ Neuropsychology of Learning

References

Deary, I. J., Penke, L., & Johnson, W. (2010). The neuroscience of human intelligence differences. *Nature Reviews. Neuroscience, 11*, 201–211.

Draganski, B., & May, A. (2008). Training-induced structural changes in the adult human brain. *Behavioural Brain Research, 192*, 137–142.

Haier, R. J., Siegel, B., Tang, C., Abel, L., & Buchsbaum, M. S. (1992). Intelligence and changes in regional cerebral glucose metabolic rate following learning. *Intelligence, 16*, 415–426.

Jung, R. E., & Haier, R. J. (2007). The parieto-frontal integration theory (P-FIT) of intelligence: Converging neuroimaging evidence. *The Behavioral and Brain Sciences, 30*, 135–154.

Kelly, A. M. C., & Garavan, H. (2005). Human functional neuroimaging of brain changes associated with practice. *Cerebral Cortex, 15*, 1089–1102.

Neubauer, A. C., & Fink, A. (2009). Intelligence and neural efficiency. *Neuroscience and Biobehavioral Reviews, 33*, 1004–1023.

Intelligent Agent

▶ Neural Network Assistants for Learning

Intelligent Communication in Animals

Zhanna Reznikova
Laboratory of Behavioural Ecology of Animal Communities, Institute of Systematics and Ecology of Animals, Siberian Branch RAS and Novosibirsk State University, Novosibirsk, Russia

Synonyms

Complex communication; Information transferring; Language behavior

Definition

What can be called "intelligent communication" or "language behavior" in animals and how does it differ from communication? The term "communication" has a wide variety of meanings, which is of no wonder, since communication is a diverse and widespread phenomenon that serves as a substance of any social behavior. Most of the signals that animals send to one another communicate the intention, emotional state, or identity of the sender. In the great majority of signaling interactions animals influence others rather than inform them. The term "language behavior" usually refers to animal communication systems in which referential signals exist that can be compared with words in a human language. Some species use distinctive signals which seem to refer to definite external stimuli, for example, types of predators or kinds of food. If such signals provide receivers with sufficient information to determine the context underlying signal production which, in turn, allows them to predict environmental events, the signals are regarded as functionally referential. "Intelligent communication in animals" can be defined as a communication that includes referential signals and means for transferring information about remote events. The most complex forms of intelligent communication possess such important properties as productivity, that is, abilities for generating potentially unlimited (or, at least, great) numbers of messages on the basis of finite number of signals, and flexibility which allow signalers and perceivers to grasp regularities in their environment and use them for optimization of messages. Some sophisticated forms of intelligent communication share with human languages the following characteristic: the length of a message is connected with the frequency of its occurrence, that is, the more frequent the message, the shorter it is (Ryabko and Reznikova 2009).

Theoretical Background

Attempts to elucidate the question whether animals can intentionally exchange meaningful messages are based on a natural idea that the complexity of communication should be connected with high levels of sociality and cooperation in animals' societies. In the 1960s and 1970s, elegant but ambiguous experiments were conducted with highly social intelligent animals, which were asked to pass some pieces of information to each other. The obtained results enabled researchers to suggest that chimpanzees possess means for transferring information about both location and properties of objects, and dolphins can coordinate each other's behavior, probably, by means of acoustic signals. Despite these supportive experiments, the question of existence of developed "languages" in nonhumans remained so far obscure.

In 1960, the linguist Charles F. Hockett proposed a list of design features of human language which separate it from animal communication, even at its most complex forms. Some of these features have been later attributed to animal language behavior expressed in nature (for instance, honeybee dance language) and in the laboratory (language-training experiments, mainly with apes): interchangeability, specialization, discreteness, arbitrariness of units, displacement (the ability to "talk" about things that are not physically present), semanticity, productivity, and elements of cultural transmission. However, the main difficulties in the analysis of animal language behavior appear to be methodological. Although many researchers have tried to directly decipher animal "languages" by looking for "letters" and "words" and by compiling "dictionaries", a combined power of different methods for studying is needed to evaluate the potential complexity of the information being transferred by animals.

Important Scientific Research and Open Questions

At least three main approaches to the problem of animal language behavior have been applied recently, and many fascinating results have been obtained by each of them (for reviews see Reznikova 2007a, b).

The first approach is aimed at direct decoding of animal signals. Decoding the function and meaning of natural communications is a notoriously difficult problem. A bottleneck here is low repeatability of standard living situations, which could give keys for cracking animals' species-specific codes, as well as difficulties with recording signals that are distinct enough and are frequently used. Up to now, there are two types of animal "languages" that have been partly deciphered: the fragments of honeybees' "dance language" and "semantic" acoustic signalizations in vervet monkeys and in several other species. In both types of communications, expressive and distinctive signals correspond to repeatable and frequently occurring situations in the context of the animals' life.

The honeybee "dance language" was discovered by K. von Frisch and confirmed in the 1990s by the use of a robotic bee. Successful forager honeybees (*Apis mellifera*) are able to recruit other bees to a distant goal by specific "dance" movements together with other components of communications such as odors and sounds. Many researchers agree now that an abstract, or symbolic, code is used to transmit the information about the direction and distance to a desired object, and this communication system meets the main Hockett's criteria. However, it is still an open question to what extent can bees display productivity and flexibility of communication.

The discovery of "semantic vocalization" in vervet monkeys (and later in some other species of primates as well as meerkats, prairie dogs, ground squirrels and several group-living bird species) was based on field playback experiments. It turned out that distinctive calls emitted by animals for different classes of predators, and even for different types of predator's behavior resulted in highly adaptive escape responses. Some animals use distinctive calls for different kinds of food, and dolphins use individually distinct whistles as referential signals among conspecifics. All these calls appeared to function as representational, or semantic, signals. It is interesting to note that Diana monkeys are able to "translate" alarm calls of sympatric chimpanzees and Campbell's monkeys, and respond to these calls with their own corresponding alarm calls; they also react adequately to combinations of elements of calls experimentally compiled by researchers. All these findings have dramatically changed the common understanding of acoustic communication in animals, which were believed to be only an expression of their current emotional status. However, this type of communication does not meet several important criteria to be considered "language-like." For instance, vervets' communication, in contrast to humans and even honeybees, does not possess displacement and productivity.

The second approach for studying natural communication of animals has been suggested based on the ideas of information theory (Ryabko and Reznikova 2009). The elaborated experimental paradigm has been applied to ants, and can be extended to other social species of animals which need to pass and memorize complex "messages." The main point of this approach is not to decipher signals but to investigate just the process of information transmission, by measuring the time duration which animals spend on transmitting messages of definite length and complexity. The scheme of experiments is based on a situation where animals must transfer a specific amount of information to each other. The crucial idea is that experimenters know exactly the quantity of information (in bits) to be transferred. In experiments with ants, to organize the process of information transmission between them, a special maze has been used, called a "binary tree," where the number and sequence of turns toward the goal (Left, L and Right, R) correspond to the amount of the information to be transferred. In order to obtain food, scouting ants had to transfer the information about the sequence of turns toward a trough with syrup. The number of bits necessary to choose the correct way was equal to the number of turns to be taken. To estimate the potential productivity of ants' "language" one can count the total number of different possible routes to the goal which is at least $2^6 = 64$ in the binary tree with six forks. Besides, seemingly with honeybees, ants are able to pass information about remote events. It is worth noting that this experimental schema provides a way for studying important characteristics of animal communication by other known methods such as the rate of information transmission and the potential flexibility of communication systems. Ants appeared to be able not only to memorize and pass each other up to 6 bits of information but also to grasp regularities in the "text" to be transferred (i.e., regular sequence LLLLLL is "simpler" than a random one, say, LLRLR) and use them to optimize their messages. This can be considered as an evidence of flexibility of ants' intelligent communication.

The third approach to studying intelligent communication is based on a direct dialogue with animals by means of intermediary languages such as gesture sign language used by deaf people, a specially designed language, based on a set of abstract symbols, and elements of human speech addressed to animals. Being applied mainly to apes, but also to dolphins, gray parrots, and even to one dog, this approach has revealed astonishing mental skills in animals. Members of all species listed above can associate abstract signs with meanings and apply "proto-grammars." Intelligent communication of apes based on artificial intermediary languages meets all of Hockett's criteria. For example, "speaking" apes generate new symbols with new meanings; use these signs to communicate simple statements, requests, and questions; refer to objects and events displaced in time and space; classify novel objects into appropriate semantic categories; and transmit their knowledge to peers and offspring. However, this way to communicate with animals is fully based on adopted human languages. Surprisingly little is known yet about the natural communication systems of the species that were involved in language-training experiments, although they displayed significant "linguistic" and cognitive potential.

Future Research

During the last decades, the combined efforts of scientists applying different experimental approaches have revealed some features of intelligent communication in animals which were earlier attributed exclusively to humans. Among them one can list animals' ability to use referential signals organized by "proto-grammatic" rules, to transfer messages in an abstract "symbolic" form, to create messages about things and events distant in time and space, to interpret messages of other species, and to extract meaningful parts from strangers' signals.

However, there are some points of discontinuity with the communicative practice of animals. Although members of several species demonstrate understanding of grammatical rules when using artificial intermediary languages, there is no evidence of syntax in the natural communication of animals. There is also little evidence of learnability and flexibility in natural communication systems of animals. There is much to be done to reveal the evolutionary roots of such a sophisticated system of communication as human language. Finally, studying the intelligent communication of animals is a good tool to judge about their cognitive abilities.

Cross-References

- ▶ Abstract Concept Learning in Animals
- ▶ Analogical Reasoning in Animals
- ▶ Animal Language Acquisition
- ▶ Animal Intelligence
- ▶ Cognitive Aspects of Natural Communication in Primates
- ▶ Imitation: Definition, Evidence, and Mechanisms
- ▶ Learning Set Formation and Conceptualization
- ▶ Linguistic and Cognitive Capacities in Apes
- ▶ Referential Vocal Learning by Gray Parrots
- ▶ Theory of Mind in Animals

References

Reznikova, Z. (2007a). Dialog with black box: Using information theory to study animal language behaviour. *Acta Ethologica, 10*(1), 1–12.

Reznikova, Z. (2007b). *Animal intelligence: From individual to social cognition*. Cambridge: Cambridge University Press.

Ryabko, B., & Reznikova, Z. (2009). The use of ideas of information theory for studying "language" and intelligence in ants. *Entropy, 11*, 836–853.

Further Reading

Hauser, M. D., Chomsky, N., & Fitch, W. T. (2002). The faculty of language. What is it, who has it, and how did it evolve? *Science, 298*, 1569–1579.

Rendall, D., Owren, M. J., & Ryan, M. J. (2009). What do animal signals mean? *Animal Behaviour, 78*, 233–240.

Seyfarth, R. M., & Cheney, D. L. (2003). Signallers and receivers in animal communication. *Annual Review of Psychology, 54*, 145–173.

Intelligent Learning Environment

▶ Neural Network Assistants for Learning

Intelligent Tutoring Systems

- ▶ Adaptive Instruction Systems and Learning
- ▶ Advanced Learning Technologies

Intense Interests

Intense interests involve a strong fascination with particular categories of objects, activities, or knowledge domains. Intense interests are similar to circumscribed and perseverative interests, though are less extreme. Intense interests are relatively long-lasting, are exhibited across different situations and contexts, and broaden over time. They are directed toward multiple objects/activities within a category of interest.

Cross-References

▶ Interest-Based Child Participation in Everyday Learning Activities

Intentional Deception

▶ Cognitive Aspects of Deception

Intentional Forgetting

▶ Directed Forgetting

Intentional Learning

Patrick Blumschein
Department of Education, University of Education, Freiburg, Germany

In contrast to latent or incidental learning, intentional learning is generally defined as learning that is motivated by intentions and is goal directed. Intentional learning gained particular attention as a result of the seminal work of Bereiter and Scardamalia (1989) on computer-supported intentional learning environments.

Bereiter and Scardamalia (1989) point out that they use the term *intentional learning* "to refer to cognitive processes that have learning as a goal rather than an incidental outcome" (p. 363). Intentional learning emphasizes the consciousness of learning. It addresses the content of learning and its end product, as well as the learning process itself. The former issue involves the learner's intrinsic motivation to work through the content and to reach the goals of learning. The latter issue, on the other hand, entails focusing on those cognitive processes that have learning as a goal.

► All experience ... can have learning as an incidental outcome, but only some cognitive activity is carried out according to procedures that contain learning goals. Whether intentional learning occurs is likely to depend on both situational and intrinsic factors – on what the situation affords in goal-attainment opportunities and on what the student's mental resources are for attaining those goals. Thus, focusing on intentional learning provides a natural way of coordinating the two relevant research traditions – the tradition dealing with learning situations and the tradition dealing with learning skills. (Bereiter and Scardamalia 1989, p. 363)

In other words: To be engaged in intentional learning the learner has to invest some effort in reflection and in controlling and maintaining learning strategies. Intentional learning can also be understood as management learning strategies and implies conscious awareness of metacognitive strategies for monitoring the learning process.

References

Bereiter, C., & Scardamalia, M. (1989). Intentional learning as a goal of instruction. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 361–392). Hillsdale: Lawrence Erlbaum.

Intentional Vocabulary Learning

In contrast to incidental vocabulary learning, intentional vocabulary learning (also called deliberate learning by some researchers) is defined as any learning activity geared at committing lexical information to memory.

Interaction

► Interactive Learning Techniques

Interaction Between Humans and Computers and Learning

► Human–Computer Interaction and Learning

Interaction of Individuals

► Social Interaction Learning Styles

Interaction Studies

► Human-Robot Interaction

Interactionism

► Meaning Development in Child Language: A Constructivist Approach

Interactive Abilities

► Interactive Skills and Dual Learning Processes

Interactive Exercises

► Interactive Learning Tasks

Interactive Image Retrieval

► Similarity Learning

Interactive Learning

Thomas C. Reeves
Department of Educational Psychology and Instructional Technology, College of Education, University of Georgia, Athens, GA, USA

Synonyms

Computer-based education (CBE); Computer-assisted instruction (CAI); Computer-assisted learning (CAL); Computer-assisted training (CBT); Interactive learning environment

Definition

All learning is interactive in the sense that learners interact with content to process, tasks to accomplish, and problems to solve with the goal of constructing improved cognitive, affective, conative, and psychomotor learning outcomes. However, in the context of the sciences of learning and especially machine learning, which are within the scope of this volume, interactive learning can be defined as a process involving some form of digitally enabled reciprocal action between a teacher or designer and a learner. Interactive learning requires access to content, tasks, and problems by at least one human being (a learner) using digital technology (e.g., a computer with Internet access). The petroleum engineer completing safety training via an online learning environment, an undergraduate student playing the role of a poverty-stricken mother in a Web-based simulation of life in a sub-Saharan African village, and a three-year-old child practicing shape identification skills with Big Bird via a Sesame Street DVD are all engaged in interactive learning. Interactive learning has also been described as any method of acquiring knowledge through hands-on activities such as when a young child uses math manipulatives (e.g., pattern blocks) to develop number sense. Interactive learning in this sense is contrasted with passive learning conceived of as simply listening to or observing others. While some authorities have suggested that some types of learning are often passive (e.g., language development), the consensus among most contemporary learning scientists is that all learning is ultimately interactive and much more social than previously conceived (Meltzoff et al. 2009).

Theoretical Background

The foundations of interactive learning reflect the full range of learning theories (behaviorist, connectionist, cognitive, constructivist, and social). B. F. Skinner's 1953 invention of a teaching machine that provided interactive learning for people via programmed instruction was an early instantiation of the principles of behaviorist learning theory. Twenty-first-century interactive learning environments such as authentic-task-based e-learning, high-fidelity medical simulations, and serious learning games are more likely to derive their design principles from contemporary constructivist and social learning theories.

There are two major approaches to implementing interactive learning in education and training contexts. First, people can learn "from" interactive learning programs, and second, they can learn "with" interactive learning tools. Learning "from" interactive learning programs is often referred to in terms such as computer-based instruction (CBI) or integrated learning systems (ILS). Learning "with" interactive software programs, on the other hand, is referred to in terms such as cognitive tools and constructivist learning environments.

An important foundation for the use of interactive learning as "tutors" (the "from" approach) is "educational communications theory" or the deliberate and intentional act of communicating content to students with the assumption that they will learn something "from" these communications. The instructional processes inherent in the "from" approach to using interactive learning systems can be reduced to four simple steps:

1. Exposing learners to messages encoded in media and delivered via an interactive technology
2. Assuming that learners perceive and encode these messages
3. Requiring a response to indicate that messages have been received
4. Providing feedback as to the adequacy of the response

The findings concerning the impact of interactive learning programs can be summed up as follows:

- Computers as tutors have modest positive effects on learning as measured by standardized achievement tests.

- Students are able to complete a given set of educational objectives in lesser time with CBI than needed in group-paced classroom instruction.
- Meta-analyses indicate that CBI has a modest effect size of less than 0.4 (Hattie 2009).
- Intelligent tutoring systems have not been as successful as predicted by earlier proponents because of technical difficulties inherent in building student models and facilitating human-like communications.

The foundation for the use of interactive learning programs as "cognitive tools" (the "with" approach) is a blend of cognitive, constructivist, and social learning design principles. Computer-based cognitive tools have been intentionally adapted or developed to function as intellectual partners to enable and facilitate critical thinking and higher order learning. Examples of cognitive tools include: databases, spreadsheets, semantic networks, expert systems, communications software such as teleconferencing programs, on-line collaborative knowledge construction environments, multimedia/hypermedia construction software, Web 2.0 social media, and computer programming languages. In the cognitive tools approach, interactive tools are given directly to learners to use for representing and expressing what they know. Learners themselves function as designers, using software tools to analyze the world, access and interpret information, organize their personal knowledge, and represent what they know to others.

The findings concerning the impact of cognitive tools can be summed up as follows:

- Cognitive tools have their greatest effectiveness when they are used to empower learners to design and revise their own representations of knowledge rather than absorbing representations preconceived by others.
- Cognitive tools are believed to have two kinds of important cognitive effects, those which are *with* the technology in terms of intellectual partnerships and those that are *of* the technology in terms of the "cognitive residue" that remains after the tools are used.
- Cognitive tools can help learners to develop project management skills, research skills, organization and representation skills, presentation skills, and reflection skills.
- Research concerning the effectiveness of cognitive tools show positive results across a wide range of less structured domains, but definitive evidence is lacking.

Important Scientific Research and Open Questions

Research on interactive learning is an important focus for educational technology and learning sciences researchers alike, and it certainly has many open, even controversial, research questions. To begin, a researcher must decide whether to view his/her interactive learning research agenda as a branch of science that is best approached using traditional experimental methods and or as a type of design craft that can be best improved through iterative cycles of formative evaluation. Clark and Mayer (2003) are among those who view interactive learning research as having a more scientific orientation; they argue that practitioners seeking guidance for the design of interactive learning programs should primarily consider studies in which "subjects [are] randomly assigned to test and control groups" (p. 45). This approach to interactive learning research is most amenable to learning environments that instantiate some form of direct instruction. Although still subject to debate, most educational researchers agree that direct instruction is most effective with well-structured domains of knowledge such as mathematics and reading skills (Tobias and Duffy 2009).

On the other hand, a researcher adopting a design craft perspective on interactive learning would argue that much of learning is focused on ill-structured domains, which are so much more complex than well-structured domains that direct instruction will inevitably be ineffective (Jonassen 2010). Rather than experimental methods, interactive learning researchers with a design craft orientation would most likely adopt educational design research methods (van den Akker et al. 2006). In addition, they would also be much more likely to focus on interactive learning variables derived from contemporary constructivist and social learning theories.

Beyond the choice of research approaches, there are numerous research questions that remain unaddressed with respect to interactive learning such as:

- What design principles can maximize the effectiveness of "from" and "with" approaches to interactive learning in well-structured and ill-structured domains?
- How can "from" and "with" approaches to interactive learning be integrated into the curriculum, teaching practices, and assessment protocols of K-12 education?

- How can interactive learning tutors be improved to the point that they match or exceed the effectiveness of human tutors?
- How can cognitive tools be integrated effectively and efficiently into interactive learning programs for education and training?

Cross-References

► Human–Computer-Interaction and Learning
► Interactive Learning Environments
► Interactive Learning Techniques
► Participatory Learning

References

Clark, R. C., & Mayer, R. E. (2003). *E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning*. San Francisco: Jossey-Bass/Pfeiffer.

Hattie, J. A. C. (2009). *Visible learning: A synthesis of over 800 meta-analyses related to achievement*. New York: Routledge.

Jonassen, D. H. (2010). *Learning to solve problems: A handbook*. New York: Routledge.

Meltzoff, A. N., Kuhl, P. K., Movellan, J., & Sejnowski, T. J. (2009). Foundations for a new science of learning. *Science, 325*, 284–288.

Tobias, S., & Duffy, T. M. (2009). *Constructivist instruction: Success or failure*. New York: Routledge.

van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). *Educational design research*. New York: Routledge.

Interactive Learning Environment

► Interactive Learning
► Model-Based Learning with System Dynamics

Interactive Learning Environments

Joseph Psotka
US Army Research Institute for the Behavioral and Social Sciences, Arlington, VA, USA

Synonyms

Adaptive learning system; Collaborative learning with emerging technologies; Computerized learning environment; Digital learning; Distributed learning environments; E-learning

Definition

An interactive learning environment (ILE) is a system built in software and sometimes with specialized hardware designed to support teaching and learning in education. The interaction in the system can be between the learner and the system, the teacher and the system, or between teachers and learners with each other using the system. The learning can be academic, informal, or work-related. The environment can be more situational and passive, as in a microworld or virtual world, or Socratic and tutorial as in an intelligent tutoring system. An ILE will normally work over the Internet as well as on mobile devices such as smart phones.

Theoretical Background

The fundamental challenge of an ILE is to produce learning using computers that rivals the best use of traditional media and environments: books, classrooms, and teachers. There is a real prospect that ILEs can even go beyond these media to improve teaching and learning. In facing this challenge, ILE strengths lie in offering unexcelled access to multimedia, databases, and text of virtually unlimited quantity and detail. Its fundamental shortcoming is twofold: that these materials are not available in organized ways that duplicate pedagogical courses and lessons; and the ILE has no semantic understanding of the materials or the students' needs and so it cannot easily adapt the materials to the user, either teacher or student. Both these shortcomings, and other less dramatic deficiencies, are being confronted in ongoing research, with varying degrees of success.

The vision of ILEs arose with computers. The first interactive computer environments were little more than word processors that turned pages for the students. However, many new capabilities that arose were quickly explored as the power and interactivity of computers exploded exponentially. Hypermedia (e.g., Kearsley and Shneiderman 1998) elevated this potential dramatically with links in pages that allowed non-linear traces through visual and text materials. By linking structured media with large-scale databases the scope of ILEs was vastly expanded and new ways were enabled to monitor students' progress and structure knowledge in ways that resembled curricula or experts' and teachers' knowledge. In another track, microworlds that hand-crafted intensive environments for exploring specific topics and skills offered unique benefits throughout education and training. Developing technologies, including smart phones and ubiquitous computing devices, are making it possible to situate ILEs in the real world where they can tap into learning on demand. The rise of the Internet and Web 2.0 offered ways of linking social networks of people distributed across the world. ILEs are used to supplement traditional face-to-face classroom activities, commonly known as Blended Learning.

Interactive learning environments in the broadest sense now encompass environments that support individual learners through to environments that support collaboration amongst groups of learners or co-workers.

Relevant domains of application include education and training at all levels, life-long learning, and knowledge sharing. Relevant research topics that address important issues that need to be improved include: adaptive systems, learning theory, pedagogy and learning design, electronically enhanced classroom, computer-mediated communications of all kinds, computer-aided assessment, design and use of virtual learning environments and learning management systems, facilitating organizational change, applying standards for courseware reuse, tracking, record keeping and system interoperability, use of learning content management systems, including workflow design and publication to a range of media, and issues associated with scaling up delivery to large cohorts of students and trainees within the corporate, educational, and other public sectors. Nothing will improve ILEs as much in the future as the automated understanding of language with underlying common sense knowledge bases that apply to all areas of education and training, especially the broad areas of instruction like English, history, geography, art, music, and foreign languages

Important Scientific Research and Open Questions

ILEs are disruptive technologies for existing educational systems. They transform education and they are very expensive to implement, both because the technologies of computers and multimedia are expensive, and also mainly because organizing knowledge into useful repositories cannot yet be automated and so demands great effort by already overworked and highly skilled educators.

The field of interactive learning environments is developing and evolving rapidly, with ongoing research that involves many broad areas of the learning sciences.

Individual Learning

- Innovative learning situations, including adaptive systems, intelligent tutoring, conversational and advisory systems
- Tools to aid learning and tools for studying and modeling learners
- Cognitive, social, developmental, and motivational aspects of how learning comes about
- Principles of course design for effective learning, authoring tools
- Self-organized learning and learning to learn

Group Activity

- Informal knowledge exchange networks
- Participation in on-line discussion
- Computer supported teamwork projects
- Collaborative learning processes
- Peer tutoring and mentoring in computer-mediated learning
- Self-assessment and peer assessment in virtual classrooms
- Interactive video and audio technologies

Social and Organizational Issues

- Facilitating and managing organizational change
- Integrating e-learning with other business processes
- The interface between e-learning and knowledge management
- Knowledge networks and social networks in communities of practice
- Blogs, discussion groups, help and advisory systems
- Virtual worlds, serious games, massively multiplayer online games

Courseware

- Authoring systems for creating ILEs
- Learning management systems
- Production processes
- The use of digital repositories
- Courseware sharing and reuse

Cross-References

- ▶ Computer Supported Collaborative Learning
- ▶ Computer-Based Learning
- ▶ Guided Discovery Learning
- ▶ Synthetic Learning Environments
- ▶ Virtual Learning Environment

References

Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *The Journal of the Learning Sciences, 4*(2), 167–207.

DeStrulle, A., & Psotka, J. (2011). Educational games and virtual reality. In W. S. Bainbridge (Ed.), *Leadership in science and technology: A reference handbook*. Los Angeles: Sage.

Kearsley, G., & Shneiderman, B. (1998). Engagement theory: A framework for technology-based teaching and learning. *Educational Technology, 38*(10), 20–23.

Lawler, R. W., & Yazdani, M. (1987). *Artificial intelligence and education: Learning environments and tutoring systems*. London: Ablex.

Meltzoff, A., Kuhl, P., Movellan, J., & Sejnowski, T. (2009). Foundations for a new science of learning. *Science, 325*(5938), 284.

Pea, R. D., & Gomez, L. (1992). Distributed multimedia learning environments. *Interactive Learning Environments, 2*(2), 73–109.

Interactive Learning Systems

▶ Interactivity in Multimedia Learning

Interactive Learning Tasks

Antje Proske, Hermann Körndle, Susanne Narciss
Psychology of Learning and Instruction, TU Dresden, Dresden, Germany

Synonyms

Interactive exercises; Interactive questions; Interactive quizzes; Interactive problems

Definition

Basically, a *task* is a piece of work to be done consisting of two elements – the question or problem and the solution. From a cognitive perspective, a task is a stimulus to which an individual responds in a certain way. Solving a task is thus an activity which requires individuals to perform a *series of cognitive processes and actions* in order to solve the problem and to produce an outcome representing the problem solution. A *learning task* is a specifically designed task in which the series of cognitive operations and actions conducing to the production of the learning task outcome lead learners to be actively engaged in knowledge construction at various levels. First, learning task processing itself can directly contribute to knowledge construction by stimulating cognitive processes which strengthen or modify learners' current mental representation of the particular subject matter. Second, learning tasks can trigger metacognitive and motivational processes devoted to learning process regulation. For example, they might provoke learners to restudy the material to be learned.

As such, learning tasks have to be distinguished from test items. Test items assess the acquired knowledge and skills and thus are not designed to promote learning. Second, the process of reaching a learning goal is often referred to as a learning task. In this sense, the "learning task" would be to learn (i.e., to direct effort and learning activities toward this goal). Learning tasks as described here do not fall into this point of view interpreting the learning process as a task, but rather have to be understood as a kind of instructional material which can help learners to reach a learning goal.

Interactive learning tasks provide learners with the possibility to interact with a system or a person during learning task processing. This interactivity supports learners in performing the necessary series of cognitive operations and actions by (a) giving them opportunities for repetition and correction, (b) tutoring learning task processing (e.g., by decomposing the problem solving process into subtasks or by delivering hints for problem solving), and (c) reciprocally reacting on learners' actions (e.g., by providing feedback). This interactivity may amplify the benefits of learning tasks for the learning process. Moreover, as working on interactive learning tasks may help learners in overcoming obstacles or in correcting incorrect solution steps, they provide mastery experiences and thus foster learners' motivation. In this way, interactive learning tasks referring to the particular material to be learned can serve as core components of computer-based learning environments.

To sum up, interactive learning tasks can be defined as follows: *Interactive learning tasks reciprocally tutor* *learners through the series of cognitive operations and actions necessary for solving a task which is specifically designed for active engagement in knowledge construction.*

Theoretical Background

Theories of instructional design (e.g., Merrill 2002) as well as theories of complex learning (e.g., van Merriënboer and Dijkstra 1997) emphasize the importance of authentic learning tasks. These theories present theoretically and empirically well-founded strategies which support instructional designers in making design decisions. One key element of these design strategies is to analyze prior to learning task creation both, what the learners will be required to do (i.e., *requirements*), as well as the *knowledge and skills* that may be helpful to meet these requirements. Subsequently, several design decisions on appropriate learner guidance including information presentation can be made.

Interactive learning tasks aim at effectively *facilitating learners' process of knowledge construction.* Several researchers agree that knowledge construction is a conscious, effortful, and resource-demanding process in which learners generate relationships: (a) among the information to be learned and (b) between the information to be learned and the learner's prior knowledge. Hence, in the case of interactive learning tasks the *requirements* are to leverage cognitive processes and actions in order to generate these relationships among information of a particular subject matter (i.e., *knowledge*). Thus, when designing interactive learning tasks the content (C) that is the subject matter of the learning task, as well as the cognitive operations (CO) and actions that are required for active knowledge construction, has to be analyzed first. The aim of this analysis is to identify those cognitive operations that should be explicitly supported in a particular subject matter by unveiling processes contributing to effective knowledge construction or faults typically made by learners lacking domain-specific or domain-general knowledge. Subsequently, learner guidance can be designed in such a way that optimal opportunities for knowledge and skill acquisition can be created by determining the interactivity (I) that tutors learning task processing and a formal dimension (F) that refers to the form and mode of the learning task (Proske et al. 2004). For example, informative tutoring feedback stepwise can provide strategically useful information that enables learners to successfully complete the task (Narciss 2008). Furthermore, in order to adapt an interactive learning task to the learners' level of prior knowledge, the CCOIF dimensions can be systematically varied (e.g., in terms of low to high complexity, more or less tutoring, or concrete to abstract presentation of the content).

Important Scientific Research and Open Questions

Research on interactive learning tasks broadly falls into two main directions: (a) construction issues and (b) effectiveness issues.

The first direction is concerned with the question of *how to build* interactive learning tasks in such a way that effective knowledge construction is stimulated and – moreover – is guided by learning task processing. Especially for computer-based learning environments efforts are made to reduce the complexity of creating and implementing interactive learning tasks. To this end, several authoring tools have been developed which enable instructional designers to realize interactive learning tasks quickly and easily without any prior technological expertise. These tools include:

(a) Commercial offline authoring tools for the development of interactive computer-based courses which also contain templates supporting quiz and exam construction (e.g., Rapid Intake ProForm™, http://www.rapidintake.com).
(b) Free web-based authoring tools for creating interactive courses including interactive quizzes (e.g., myUdutu™ online authoring tool, http://udutu.com/).
(c) Commercial assessment tools especially designed for creating and managing exams (e.g., Respondus, http://respondus.com, Articulate Quizmaker, http://www.articulate.com/products/quizmaker.php).
(d) Free offline tools supporting the creation of web-based interactive learning tasks (e.g., Hot Potatoes, http://hotpot.uvic.ca/index.php, EF-Editor, http://studierplatz2000.tu-dresden.de/efb).

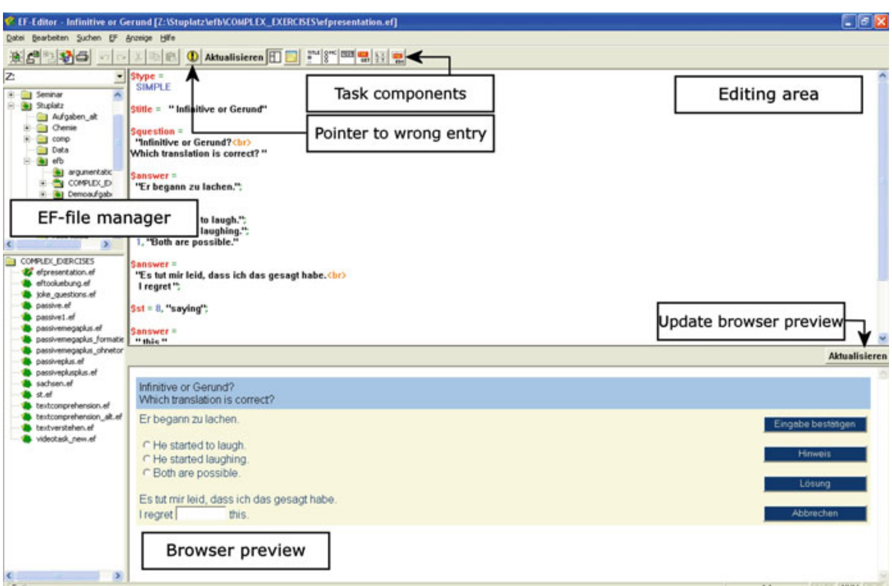
In order to guarantee that the particular authoring tool can be used by a widespread audience of instructional designers, these tools provide many facilities for creating several basic types of interactive learning tasks including feedback. The consequence, however, is that these authoring tools cannot provide much guidance to the instructional designer in making design decisions aiming at facilitating learners' knowledge construction. In contrast, the free offline authoring tool *Exercise Format Editor* (EF-Editor, http://studierplatz2000.tu-dresden.de/efb) has been developed by explicitly taking into account that decisions have to be made with respect to the CCOIF dimensions (cf. Proske et al. 2004).

The EF-Editor supports the generation of files in the file format *Exercise Format (EF)*. EF is a plain text file format in which the data constituting an interactive learning task can be saved. To this end, the instructional designer has to determine at least five task components: (a) the question, (b) text fragments within the working area, (c) the response format(s), (d) content that is related to interactive buttons (e.g., tutoring information), and (e) the correct solution(s).

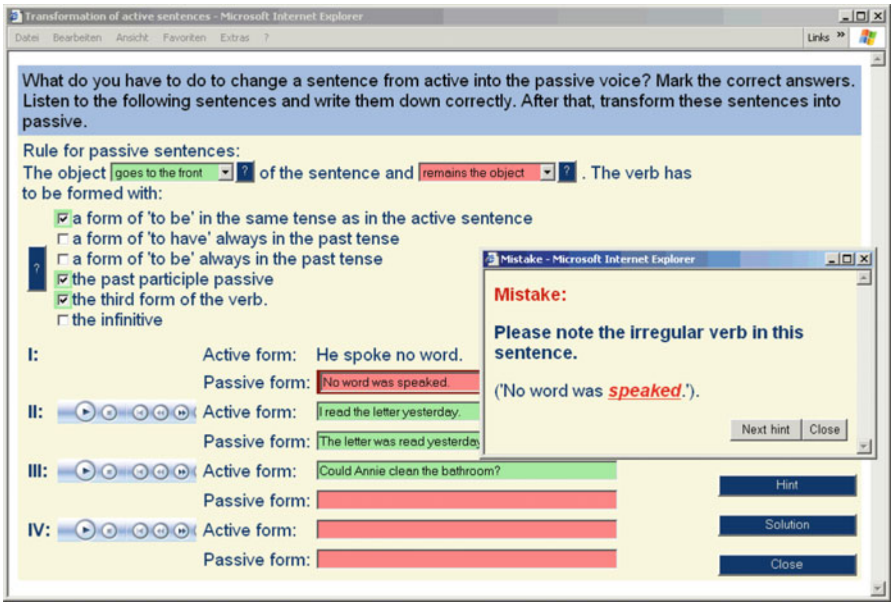
The task components have to be written down in the *Editing area* of the EF-Editor. These entries, as well as the task functioning, can be immediately checked in the *Browser preview* by clicking on the *Update* button. On the top of the screen a yellow exclamation mark appears in case of a wrong entry. Information related to the kind and location of the wrong entry is given by clicking on this icon (see Fig. 1).

In order to integrate interactivity, the EF-Editor encourages the integration of several tutoring information. Tutoring information either can be provided for the whole learning task (via the button *Hint)*, or related to specific task parts (via the buttons with the interrogation mark, see Fig. 2). Furthermore, informative tutoring feedback (Narciss 2008) is automatically included into the learning tasks: If a learner gives an answer to the task, the system in a first step provides information on the correctness of the answer (i.e., knowledge of result) and offers a second try in case the response was incorrect. Is the question incorrectly answered for the second time, correctly solved task parts are tagged green, incorrectly solved parts are tagged red, and an evaluation of overall performance is provided. If the learner fails again by making a mistake foreseen by the instructional designer during task creation, tutoring information tailored to this specific mistake is delivered successively.

With respect to learning task form and mode, it is possible to integrate all kinds of materials that can be handled by a web browser. The basic formats of the EF-Editor span from simple short answer and multiple-choice items across several types of completion texts to complex types of matching tasks (http://linus.psych.tu-dresden.de/Stupla/ef/doc/ef.htm#examples). All basic formats can be combined. Furthermore, the



Interactive Learning Tasks. Fig. 1 The EF-editor's user interface



Interactive Learning Tasks. Fig. 2 Learning task including tutoring information for a mistake (wrong use of an irregular verb in the first sentence) foreseen by the instructional designer

basic formats can be integrated into complex task types which decompose a comprehensive interactive learning task into its subtasks by either presenting the subtasks stepwise or on file cards (http://linus.psych.tu-dresden.de/StuPla/ef/Demoaufgaben/index.html). The EF-Editor also provides different templates that enable the instructional designer to create interactive learning tasks in several appearances, languages, and for several purposes.

Thus, the EF-Editor provokes instructional designers to make several design decisions with respect to the CCOIF dimensions and supports the realization of these decisions. However, not all steps necessary for the design of interactive learning tasks are supported by now. Yet, developing useful interactive learning tasks requires considerable effort from the instructional designer, particularly in analyzing the subject matter and the cognitive operations that should be stimulated and guided through learning task processing. Therefore, further research is needed in order to develop authoring tools which are tailored specifically to guide the authoring process of such interactive learning tasks.

The second main research direction focuses on *factors affecting the effectiveness of interactive learning tasks* in computer-based learning environments. Traditional research on learning tasks in the context of prose learning and adjunct questions (i.e., questions added to instructional text) has proven that working on learning tasks can guide the learning process and facilitate learners' retention and understanding of the content targeted within the questions (e.g., Anderson and Biddle 1975). These positive effects were particularly found for questions that require simple cognitive processes such as recall or recognition. In contrast, solving complex authentic tasks offers learners much more opportunities for successful knowledge construction. Up to now, research on complex learning tasks mainly investigated task sequencing and amount of guidance. As a result, many researchers suggest a progression from simple to complex. In addition, guidance for task processing should be high in the beginning and gradually fade out as the learner proceeds (e.g., Merrill 2002; van Merriënboer and Dijkstra 1997). Some studies dealt with other questions, such as when to present interactive learning tasks (before, while, after learning the material), or which surface characteristics (e.g., task format, length of question) or learner characteristics (e.g., attitudes, intentions, prior knowledge) influence learning process and outcome. So far, these latter studies are too few as they can serve for deriving convincing design recommendations. Thus, although the prominent role of interactive learning tasks in computer-based learning environments seems to be evident, there are many open questions left which deserve further research.

Cross-References

▶ Adjunct Questions
▶ Cognitive Tasks and Learning
▶ Computer-Based Learning Environments
▶ Feedback Strategies
▶ Four-Component Instructional Design
▶ Learning Tasks
▶ Self-regulated Learning

References

Anderson, R. C., & Biddle, W. B. (1975). On asking people questions about what they are reading. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 9, pp. 89–132). New York: Academic Press.

Merrill, M. (2002). First principles of instruction. *Educational Technology Research and Development, 50*(3), 43–59.

Narciss, S. (2008). Feedback strategies for interactive learning tasks. In J. M. Spector, M. D. Merrill, J. J. G. van Merrienboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 125–144). Mahwah: Lawrence Erlbaum.

Proske, A., Körndle, H., & Narciss, S. (2004). The exercise format editor: A multimedia tool for the design of multiple learning tasks. In H. Niegemann, D. Leutner, & R. Brünken (Eds.), *Instructional design for multimedia learning* (pp. 149–164). Münster: Waxmann.

van Merriënboer, J. J. G., & Dijkstra, S. (1997). The four-component instructional design model for training complex cognitive skills. In R. D. Tennyson, N. Seel, S. Dijkstra, & F. Schott (Eds.), *Instructional design: International perspectives* (Vol. 1, pp. 427–445). Hillsdale: Lawrence Erlbaum.

Interactive Learning Techniques

Thomas C. Reeves
Department of Educational Psychology and Instructional Technology, College of Education, The University of Georgia, Athens, GA, USA

Synonyms

Engagement; Feedback; Interaction

Definition

Interactive learning techniques encompass the repertoire of instructional strategies that can be incorporated into interactive learning environments to enable learning to occur. There are three key components that must be included in every interactive learning technique: engagement, interaction, and feedback. First, the learner must be motivated, either intrinsically or extrinsically, to engage with the content to process, tasks to accomplish, and/or problems to solve that are at the core of any interactive learning environment. Second, the learner must be enabled to interact with the relevant content, tasks, and problems in ways that can be clearly understood by the learner as well as by the digital system. Third, the decisions and actions the learner takes within an interactive learning environment must be recognized by the digital system and acknowledged through meaningful feedback and assessment.

Theoretical Background

The foundations of interactive learning techniques are many and varied. The most dominate type of interactive learning technique is somewhat ironically known as direct instruction. Although some have unfairly characterized direction instruction as little more than "teachers talk while students listen," Hattie (2009) states that direct instruction must include at least seven steps to be effective: (1) clear learning intentions, (2) unambiguous success criteria, (3) learner commitment and engagement, (4) direct instructional presentation strategies, (5) guided practice, (6) closure, and (7) independent practice. Direct instruction has most often been characterized as a technique that is best implemented by a human teacher, but compelling models for how this learning technique can be actualized using digital technology have been developed and tested (van Merriënboer 1997).

Numerous other interactive learning techniques have been developed and studied for decades such as:

- Programmed instruction
- Reciprocal teaching
- Inductive teaching
- Inquiry-based teaching
- Problem-based learning
- Project-based learning
- Cooperative learning

- Collaborative learning
- Discovery learning
- Authentic learning

Just as with the direct instruction technique, each of these other interactive learning techniques has a specific set of design principles that constitute how the technique should be implemented. For example, Herrington et al. (2010) prescribe the following interactive learning design principles for the development of authentic e-learning:

1. Provide authentic contexts that reflect the way the knowledge will be used in real life
2. Provide authentic activities
3. Provide access to expert performances and the modeling of processes
4. Provide multiple roles and perspectives
5. Support collaborative construction of knowledge
6. Promote reflection to enable abstractions to be formed
7. Promote articulation to enable tacit knowledge to be made explicit
8. Provide coaching and scaffolding by the teacher at critical times
9. Provide for authentic assessment of learning within the tasks.

Authentic tasks as a foundation for the design of e-learning programs have been shown to be engaging and effective across a wide variety of curricular disciplines, but these research findings are primarily based on interpretivist studies using qualitative methods rather than on quasi-experimental studies using quantitative methods (Herrington et al. 2010).

Important Scientific Research and Open Questions

For more than 20 years, disagreements among educational researchers and learning theorists about the relative merits of different interactive learning techniques based upon behavioral, cognitive, and constructivist principles have persisted (Tobias and Duffy 2009). A noteworthy contribution to this scholarly debate was made by Kirschner et al. (2006), long time proponents of "direct instruction," in the journal *Educational Psychologist*. This controversial article stimulated several rebuttal papers, a special panel session at the 2007 convention of the American Educational Research Association in Chicago, and an edited volume of papers (Tobias and Duffy 2009). This debate has raised a host of stimulating research questions such as:

- What is the nature of learning outcomes?
  - The processing, storage, and retrieval of information in memory
  - A relatively permanent change in behavior or behavioral dispositions
  - Some sort of conceptual change
  - The development of mental models
  - The capacity to engage in effective problem solving
  - The ability to engage in lifelong learning
  - The refinement of interpersonal negotiation skills
- Which interactive learning techniques are most effective for different types of learning outcomes?
- How do individual student characteristics interact with different types of interactive learning techniques?

It is highly unlikely that these and related research questions can be answered in ways that matter using either interpretivist or experimental methods. Instead, a type of design-based research method appears to be much more promising with respect to dealing with the complexity of the variables inherent in the application of interactive learning techniques (van den Akker et al. 2006).

Cross-References

► Interactive Learning
► Learning Strategies
► Learning Tasks

References

Hattie, J. A. C. (2009). *Visible learning: A synthesis of over 800 meta-analyses related to achievement.* New York: Routledge.

Herrington, J., Reeves, T. C., & Oliver, R. (2010). *A guide to authentic e-learning.* New York: Routledge.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Tobias, S., & Duffy, T. M. (2009). *Constructivist instruction: Success or failure.* New York: Routledge.

van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). *Educational design research.* New York: Routledge.

van Merriënboer, J. J. G. (1997). *Training complex cognitive skills: A four-component instructional design model for technical training.* Englewood Cliffs: Educational Technology.

Interactive Media

► Interactivity in Multimedia Learning

Interactive Multimodal Learning Environments

► Interactivity in Multimedia Learning

Interactive Pedagogical Dramas

► Narrative-Centered Learning Environments

Interactive Problems

► Interactive Learning Tasks

Interactive Questions

► Interactive Learning Tasks

Interactive Quizzes

► Interactive Learning Tasks

Interactive Reinforcement Learning

► Robot Learning from Feedback

Interactive Skills and Dual Learning Processes

Wai-Tat Fu[1], Jessie Chin[2], Wei Dong[1], Q. Vera Liao[1]
[1]Computer Science and Human Factors, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, USA
[2]Department of Educational Psychology, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, USA

Synonyms

Dual enrollment; Interactive abilities

Definition

Interactive skills refer to the general ability to interact with the external world to accomplish a task. A typical interactive task requires the person to look for relevant information and choose the right actions. The complexity of an interactive skill increases as (1) the uncertainty of the outcome of an action increases, (2) when the mapping between recognizable cues and actions becomes more complex, and (3) when there is interdependency between actions and outcomes. An interaction skill involves both explicit and implicit learning processes, and the effectiveness of each kind of process depends on the complexity of the skill. Explicit learning processes refer to processes that require focused attention and involve information that can be verbalized and communicated. Implicit learning processes do not require focused attention and involve information that cannot be easily verbalized and communicated.

Theoretical Background

An important aspect of interaction skill is the ability to utilize the right cues to select the right actions. Cues are patterns of information relevant for a task. Cues can be external and directly perceived (e.g., seeing a red light and deciding to stop), or they can be internal and need to be first encoded in memory and retrieved at a later time when they are needed (e.g., remembering where we park our car). The acquisition of an interactive skill involves the association between internal and external cues and actions. An interactive skill becomes more complex as the associations become probabilistic, interdependent, or both.

The simplest form of an interactive skill is cue-action association (the cue could be either internal or external). For instance, humans can learn to associate an action with a particular cue by observing how likely a cue-action association can reach a satisfying state of affairs (the law of effect; Thorndike 1911). A person can then learn to associate an action with the presence of an external cue, such that when the external cue is presented again, the right action can be selected. This simple form of interactive skill acquisition can be done by both the explicit and implicit process. However, empirical studies show that explicit process is often suppressed when additional constraints are imposed, such as when a demanding external task is present, which makes explicit learning of cue-action association difficult (Fu and Anderson 2008a, b; Keele et al. 2003).

An interactive skill becomes more complex when the cue-action associations are probabilistic, such that, for example, cue-action1 is 80% correct and cue-action2 is 20% correct in an environment. Learning in such probabilistic environment is difficult because when the cue is present, the person cannot simply remember the last correct action (which can be either action1 or action2). Rather, the person needs to accumulate experiences and select actions that are in general more frequently correct in the past. This form of learning is often referred to as *reinforcement learning* (Sutton and Barto 1998). In general, reinforcement learning accumulates reward signal for each action after its execution, and selects action that has the highest accumulated reward. Recent studies in neuroscience have shown that the reward signals in reinforcement learning resemble dopamine activities in the basal ganglia when humans are learning probabilistic cue-action associations (Waelti et al. 2001). Given that the basal ganglia is often considered to be responsible for implicit learning of cue-action association, it is often believed that learning of probabilistic cue-action association can be accomplished by implicit learning, and this hypothesis is shown to be consistent with results from behavioral studies.

The complexity of an interactive skill increases when immediate feedback is not available (e.g., when one is navigating in an unfamiliar neighborhood). In that case, one has to learn from delayed reward. In other words, when the delayed reward is received, it needs to be assigned to a previous cue-action pair that led to the reward. This creates a credit-assignment problem, as feedback is received only after an action sequence is executed, and it is not clear which particular action leads to the correct (or incorrect) outcome. In animal research, feedback is often implemented by explicit reward. However, explicit learning can occur without explicit feedback. For example, research in latent learning, in which rats learned the cognitive map of the maze implicitly and was able to later implement its knowledge without the presence of rewards (Tolman 1932).

Empirical studies show that there are distinct processes that perform the credit assignment of actions when learning from delayed feedback (Fu and Anderson 2008a, b). In the explicit process, cues and actions are first encoded into memory, and when the feedback is received, the cues and actions are retrieved and credits (positive or negative reward) can be assigned to them. In this kind of implicit learning, credits are first assigned to the cue-action that is closest to the feedback, and the credit will subsequently propagated back to earlier cue-action associations. This credit propagation process is shown to match well with a reinforcement learning process (Fu and Anderson 2006). Results from empirical studies show that the implicit reinforcement learning process can remain relatively effective even when attentional resources are drawn to a demanding secondary task (Keele et al. 2003).

Interactive skills become even more complex when there are interdependencies between sequential actions. Interdependency refers to the situations in which cues and actions in the environment are dependent on prior actions. In such situations, learning is difficult because one has to remember prior actions (and cues) before the right actions can be selected. Remembering prior cues or actions can be done by an explicit encoding process. However, when the explicit process is suppressed (e.g., by a demanding secondary task), learning of interdependent action sequences can sometimes be accomplished implicitly when external cues are present, which allow credits to propagate back from the final feedback to prior actions through the external cues. It has been shown that when consistent external cues are present, implicit reinforcement learning is sufficient to allow acquisition of interactive skills in which interdependency of actions exist. However, when consistent external cues do not exist, implicit reinforcement learning will fail, and people may simply fail to learn to select the correct action sequence in such situations (Fu and Anderson 2006).

Important Scientific Research and Open Questions

The idea that information is processed through two distinctive routes, one that requires explicit encoding, the other undergoes implicit reinforcement learning, is not limited to the acquisition of interactive skills. In fact, dual-processing theories can be found in a wide range of research, including research on persuasion, judgment and decision making, and neuroscience. For example, in the area of persuasion, researchers have studied how different information may lead to change in beliefs and attitudes (Petty and Cacioppo 1986). Although differences exist, these dual process models shared a fundamental consensus that external information cues are processed through a central route that systematically deliberate on the information content, and a peripheral route that relies more on heuristics, experience or/and emotion. In general, the explicit route demands more cognitive resources than the implicit route. When individuals lack either motivation or ability to perform systematical evaluation or deliberation on the information contents, they tend to rely more on the implicit route to learn, make decisions, or change their attitude.

One important application of dual processing models is to understand how individual differences that are relevant to either of the two processes influence people's learning, attitude change, or decision-making outcomes. For example, aging is one of the factors being widely studied for its effects on explicit and implicit processes. Several lines of research provide robust evidence of age-related declines in deliberative/explicit system. It is shown that older adults performed generally worse in tasks that require systematic learning due to their lower information processing speed, age-related deficits in explicit memory, working memory, and executive functions. However, the age difference in implicit learning and memory is found to be small. In terms of decision making, research showed that older adults tend to selectively use their explicit processes based on their level of motivation to make the decision; so when the information is less meaningful or relevant to them, they are less likely to explicitly process the contents to make the decision. Research also shows that older adults who are relatively more likely influenced by implicit cues that are related to their emotions than do younger adults. However, the role of this implicit/affective processing is somewhat less clear since it may involve both explicit and implicit information processing, and more research is needed to clarify the interaction of implicit/affective processing and age-related changes such as decline in cognitive abilities.

Although research has demonstrated the existence of the explicit and implicit learning processes, how exactly these processes are orchestrated in different situations is still unclear. It is not clear, for example, whether both processes would occur in parallel and the relative effect of each kind of process will manifest itself in different situations, or whether one process may dominate the other one and influence behavior under different situations. More research is needed to understand how the two processes may be moderated by external (environmental) and internal (individual differences in cognitive abilities, experiences, etc.) factors.

Cross-References

► ACT (Adaptive Control of Thought)
► Attention and Implicit Learning
► Basal Ganglia Learning
► Dual Process Models of Information Processing
► Implicit Sequence Learning
► Procedural Learning
► Reinforcement Learning

References

Ballard, D. H., Hayhoe, M. M., Pook, P. K., & Rao, R. P. N. (1997). Deictic codes for the embodiment of cognition. *The Behavioral and Brain Sciences, 20*, 723–742.

Fu, W.-T., & Anderson, J. R. (2006). From recurrent choice to skilled learning: A reinforcement learning model. *Journal of Experimental Psychology: General, 135*, 184–206.

Fu, W.-T., & Anderson, J. (2008a). Solving the credit assignment problem: Explicit and implicit learning of action sequences with probabilistic outcomes. *Psychological Research, 72*, 321–330.

Fu, W.-T., & Anderson, J. (2008b). Dual learning processes in interactive skill acquisition. *Journal of Experimental Psychology: Applied, 14*, 179–191.

Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review, 109*, 679–709.

Keele, S., Ivry, R., Mayr, U., Hazeltine, E., & Heuer, H. (2003). The cognitive and neural architecture of sequence representation. *Psychological Review, 110*, 316–339.

Petty, R. E., & Cacioppo, J. T. (1981). *Attitudes and persuasion: Classic and contemporary approaches*. Dubuque: Wm. C. Brown.

Petty, R. E., & Cacioppo, J. T. (1986). The elaboration likelihood model. *Advances in Experimental Social Psychology & Aging, 19*, 123–205.

Sutton, R. S., & Barto, A. G. (1998). *Reinforcement learning: An introduction*. Cambridge: MIT Press.

Thorndike, E. L. (1911). *Animal intelligence: Experimental studies.* New York: Macmillan.
Tolman, E. C. (1932). *Purposive behavior in animals and men.* New York: Century psychological series.
Waelti, P., Dickinson, A., & Schultz, W. (2001). Dopamine responses comply with basic assumptions of formal learning theory. *Nature, 412*, 43–48.

Interactive System

As opposed to noninteractive systems and media, interactive systems and media require user input within a larger governing system of rules for functionality and message transmission.

Interactive Virtual Reality Learning Environments

► Virtual Reality Learning Environments

Interactivity

► Action-Based Learning
► Video-Based Learning

Interactivity in Multimedia Learning

Jan L. Plass[1], Ruth N. Schwartz[1], Steffi Heidig (née Domagk)[2]
[1]Consortium for Research and Evaluation of Advanced Technologies in Education (CREATE), New York University, New York, USA
[2]Learning and Interactive Media, Department of Education, University of Erfurt, Erfurt, Germany

Synonyms

Interactive learning systems; Interactive media; Interactive multimodal learning environments

Definition

The literature on multimedia learning offers a number of definitions of interactivity, each emphasizing different aspects of the concept. This inconsistency is due in part to the fact that the term interactivity is used in a broad range of fields, including advertising, the arts, information systems, communication, marketing, and educational psychology. Across these fields, three main approaches can be distinguished: (1) interaction in human communication, stemming from a sociological tradition, (2) computer-mediated human communication, originating in mass communication approaches, and (3) human–computer interaction, derived from computer science but also applied in the field of educational technology and the learning sciences.

Definitions from these different perspectives agree that interactivity requires two fundamental conditions: (1) at least two participants must interact with each other, and (2) the actions of these participants must include an element of reciprocity, that is, change needs to occur on both sides: The actions of one party trigger responses from the other, which lead in turn to changes in the first. Johnson, Bruner & Kumar (2006) further specify that it is not only reciprocity that is required for interactivity, but also responsiveness – actions and reactions on both sides must be related, relevant, and sustain the continuity of the interaction.

In the context of multimedia learning, defining interactivity from the perspective of human–computer interaction seems most appropriate. Applying the two fundamental conditions of interactivity identified above allows for a general definition of the concept of interactivity:

► *Interactivity in the context of computer-based multimedia learning is reciprocal activity between a learner and a multimedia learning system, in which the [re]action of the learner is dependent upon the [re]action of the system and vice versa.* (Domagk, Schwartz & Plass 2010).

This definition emphasizes the dynamic relationship between the learner and the learning system. It further acknowledges that a multimedia learning environment is not interactive *per se*, but rather that features of the environment have the potential to engage the learner. The learner must release this potential by responding to system activity in a meaningful way (Kennedy 2004).

Theoretical Background

With the advent of readily accessible computer technology in the 1980s came the anticipation of new possibilities for its use in education, in particular its capacity for providing interactive learning experiences. Interactivity, it was predicted, would allow learning materials to be individualized in an unprecedented manner, with opportunities for learners to choose content, level of difficulty, and mode of presentation, as well as to receive customized feedback, elaboration, and assessment (Hannafin 1989). As a result of individualization, it was believed, learner engagement would increase and learning outcomes would improve. Hannafin (1989) suggested that such improvement might be quantitatively based, arising from the number of opportunities to respond and receive feedback, or qualitatively based, resulting from the manner in which interactive environments support cognitive processing.

Early interest in interactivity as a critical component of multimedia learning was consistent with an historical emphasis on active learning and learner participation in education. Such discussions have continuous, well-established roots in educational theory and philosophy, with emotional and behavioral as well as cognitive engagement often emphasized as basic to learning. For example, both the seventeenth century thinker John Locke and Jean-Jacques Rousseau in the eighteenth century suggested that children's eagerness to learn could be a powerful force in their education. In the early years of the nineteenth century, Swiss educator Johann Pestalozzi stressed that children should interact with specific physical objects in order to foster development of abstract ideas; his disciple Friedrich Fröbel conceived of the idea of the modern kindergarten, designed around activities involving a graduated series of manipulative materials and tasks. To these educators, physical actions were critical in the development of the child's intellect. Similarly, early twentieth century educational theorists such as Maria Montessori and John Dewey ascribed great importance to interacting with concrete objects and engaging in active pursuits in order to develop abstract thought. Dewey cautioned, however, that physical activity in itself is not sufficient; for learning to occur, the mind must also be fully engaged. Vygotsky, in the same time period, as well as Bruner, somewhat later in the twentieth century, emphasized that cognitive activity is, in general, situated in interactions between the individual and the environment, including experiences, perceptions, actions, language, and culture. Constructivist approaches to learning, which share the assumption that the learner is an active and responsible agent in the construction of knowledge, are the most recent expression of these ideas. Interactive multimedia learning environments, which offer, or even require, a newly active role for learners, seem a natural fit for such approaches (Schwartz 2010).

Contemporary views of interactivity in multimedia learning continue to emphasize many of the same strengths initially heralded. The introduction of interactive features is believed to promote the active engagement of learners, allowing learner control of various elements of instruction as well as offering targeted prompts, scaffolding, and feedback (Renkl and Atkinson 2007). The interactive features most commonly discussed in theory and investigated in current empirical studies include learner control, such as pacing or manipulation of content; guidance; and feedback. Although various findings identify general benefits of interactive environments, the generalizability of such results suffers from the lack of a broadly adopted definition of interactivity and from the absence of a widely accepted method of operationalizing interactivity in multimedia learning environments. The lack of a standardized approach has resulted in several distinct lines of research, such as studies that compare interactive to "traditional" learning environments, studies in which interactive features are either present or absent, or studies that examine variations of specific interactive features.

Important Scientific Research and Open Questions

Various approaches to the operationalization of interactivity have been proposed. Most fall into one of two broad categories: *technological and functional* perspectives or *psychological and learner-centered* perspectives.

Technological classifications of interactivity focus on the learning system, operationalizing it in terms of delivery media (e.g., web, videoconferencing, VoIP), input devices (e.g., keyboard, mouse, touch screen, controllers) or features provided (e.g., hypertext, simulations, multimedia). Functional approaches focus not only on the affordances of the learning systems, but also on their potential to engage the learner in behavioral activities. Prominent taxonomies of interactivity from a functional perspective have been introduced by Schwier and Misanchuk (1993) as well as Sims (1997).

Psychological perspectives on interactivity shift the emphasis to the learner rather than the learning system. Early approaches that address learners' cognition specify instructional strategies to be implemented in interactive media (e.g., Hannafin 1989; Jonassen 1985). Recent discussions of interactivity in multimedia learning contend that a system-centered approach is of only limited use for research on the effectiveness of interactivity; it is not actions within the system, but the cognitive processes elicited which are of primary importance (Renkl and Atkinson 2007). The resulting typologies of interactivity, however, continue to incorporate aspects of the functional approach rather than focusing on the learner's cognitive processes.

Both functional and psychological approaches to operationalizing interactivity aim at classifying learning environments as more or less interactive, with the assumption that a higher degree of interactivity may facilitate learning. However, this assumption is contested; a cognitive load perspective, for example, suggests that, under some conditions, increased interactive options could impose a level of extraneous cognitive load that might impede learning.

Viewing interactivity as a dynamic process between a learner and a learning system suggests that approaches should not be limited to either the affordances of the learning system or the cognitive processes of the learner. A process model of multimedia interactivity that incorporates the learner's behavioral, cognitive, and affective activities as well as the affordances of the learning system and characteristics of learners, such as prior knowledge, self-regulation, and affective traits, were introduced by Domagk et al. (2010), based on an earlier model by Kennedy (2004). The model, known as INTERACT, comprises six components that are linked by continuous feedback loops: the learning environment, the learner's behavioral activities, cognitive and metacognitive activities, emotional and motivational states, learner characteristics, and the learner's mental model. Consistent with historical views of engaging learners in their own learning, this model includes behavioral and emotional as well as cognitive factors. The INTERACT model can be applied to inform research and to reconceptualize typically discussed constructs in the context of interactivity in multimedia learning such as learner control, feedback, and guidance.

Cross-References

► Computer-Based Learning
► Constructivism
► Emotions and Learning
► Interactive Learning Environments
► Interactive Learning Tasks
► Learner Characteristics
► Learner Control
► Motivation and Learning
► Multimedia Learning

References

Domagk, S., Schwartz, R. N., & Plass, J. L. (2010). Interactivity in multimedia learning: An integrated model. *Computers in Human Behavior, 26*, 1024–1033.

Hannafin, M. J. (1989). Interaction strategies and emerging instructional technologies: Psychological perspectives. *Canadian Journal of Educational Communication, 18*(3), 167–179.

Johnson, G. J., Bruner, G. C., & Kumar, A. (2006). Interactivity and its facets revisited. *Journal of Advertising, 35*(4), 35–52.

Jonassen, D. H. (1985). Interactive lesson designs: A taxonomy. *Educational Technology, 25*(6), 7–17.

Kennedy, G. E. (2004). Promoting cognition in multimedia interactivity research. *Journal of Interactive Learning Research, 15*, 43–61.

Renkl, A., & Atkinson, R. K. (2007). Interactive learning environments: Contemporary issues and trends. An introduction to the Special Issue. *Educational Psychology Review, 19*, 235–238.

Schwartz, R. N. (2010). Considering the activity in interactivity: A multimodal perspective. Ph.D. dissertation, New York University, New York. Dissertations & Theses, New York University (Publication No. AAT 3404551).

Schwier, R. A., & Misanchuk, E. R. (1993). *Interactive multimedia instruction*. New Jersey: Educational Technology Publications.

Sims, R. (1997). Interactivity: A forgotten art? *Computers in Human Behavior, 13*(2), 157–180.

Intercultural Development

► Intercultural Learning

Intercultural Issues in Music Education

► Multicultural Issues in Music Instruction and Learning

Intercultural Learning

H. Chad Lane
Institute for Creative Technologies, University of Southern California, Marina Del Rey Los Angeles, CA, USA

Synonyms

Intercultural development; Intercultural skill acquisition; Intercultural transformation

Definition

Intercultural learning refers to the acquisition of knowledge and skills that support the ability of learners to both understand culture and interact with people from cultures different from their own. It is developmental in the sense that learners advance through stages of progressively more sophisticated levels of understanding. This understanding includes that of different cultures as well as their own. Specifically, to develop cultural awareness, it is important for a learner to have this sense of *cultural self-awareness*, which will form the basis for comparisons that are inevitably made by the learner. Intercultural training can be designed to be *culture specific* by dealing with a single target culture, such as Japanese, or *culture general* by focusing on universally applicable skills, such as perspective taking and active listening. Development of intercultural competence can be a lengthy and stressful process for many as it requires a complex blend of cognitive, emotional, and attitudinal change to occur.

Theoretical Background

Since World War II, steady increases in international business, travel, education, and diplomacy have created widespread interest in intercultural learning. Countless business and military training programs on cultural awareness and intercultural communication have been created, as well a large body of interdisciplinary academic research. Acquiring intercultural knowledge and skills represents a special category of learning that requires consideration of cognitive, emotional, behavioral, and attitudinal factors. While no single definition of culture or method of training for intercultural competence has emerged as clearly dominant, significant progress has been made in both explaining the psychological processes involved with cultural learning and designing effective intercultural instruction (Landis et al. 2004).

Edward T. Hall, an anthropologist, is often credited as the first intercultural communication researcher and for providing basic definitions of culture and cultural values that underlie contemporary research on intercultural learning (Hall 1959). Unfortunately, early models of intercultural learning and teaching tended to take a relatively static view of culture focusing primarily on “facts” and simple behavior adjustments. Coinciding with more rigorous study of intercultural learning and development, a more nuanced view emerged that recognized the dynamic nature of culture in society, one of constant change, and of human creation (Landis et al. 2004). What is learned during intercultural development generally falls into three broad categories. The first is *knowledge*, which includes the standard declarative and procedural representations necessary for human cognitive learning, and basic, culturally related classification skills. Some examples are basic facts about a new culture, such as common values and beliefs, preferences for physical contact, and typical eating and drinking patterns. The second category is *behavior*. This covers skills such as interpersonal communication, problem solving, coping, and so on, in cultural contexts. Finally, *attitude* involves the learner’s subjective views of other cultures and people from them. A positive, neutral, or negative disposition toward a different culture can profoundly influence one’s ability to learn about it and progress to the more advanced stages of intercultural development.

Models of intercultural development and learning generally assume that learning occurs in stages and can take many years. Empirical evidence provides strong support for this assumption. Whether it be a student studying abroad or a business executive starting a new branch in a foreign country, the assumption that people acclimate gradually is both intuitive and generally supported by psychometric and cognitive measures of intercultural development (Landis et al. 2004). A variety of models has been proposed to explain how people acquire intercultural knowledge and skills, as well as how development occurs in stages over time.

One of the more mature theories of intercultural learning is Milton Bennett’s (1993) Developmental Model of Intercultural Sensitivity (DMIS). The DMIS rests on the assertion that as one’s ability to construe cultural differences evolves, intercultural competence also increases. According to Bennett, "it is the construction of reality as increasingly capable of accommodating cultural difference that constitutes development" (Bennett 1993, p. 24). The DMIS posits that people assume one of two worldview orientations: *ethnocentrism* and *ethnorelativism*. Specifically, these refer to the positioning of one's own culture in relation to others. An ethnocentric orientation implies that one perceives all other cultures relative to his or her own (i.e., that it is central to reality), whereas an ethnorelative perspective implies that one's own culture is understood in the context of others. Intercultural learning can be understood as movement from an ethnocentric orientation to an ethnorelative one. Bennett describes three substages within each orientation that describe common cognitive and affective states that arise during development. The first ethnocentric stage is *denial of difference* in which the learner ignores or neglects differences. The next stage is *defense against difference*, which includes recognition of cultural difference, but with negative evaluation. This stage is characterized by an "us vs. them" mindset and overt, negative stereotyping. The last ethnocentric stage is *minimization of difference* and includes the first signs of recognizing another cultural worldview. In this stage, the learner emphasizes similarities between cultures and recognizes only superficial cultural differences. Comments such as "we are all the same" are common at this stage. Guidance is especially important because some learners believe that minimization is the ultimate stage of growth. When reality sets in that cultural differences are truly significant, there is a risk of withdrawal (Bennett 1993, p. 44). The shift to an ethnorelative orientation is characterized by a basic understanding that one's culture is but one out of many valid worldviews. It begins with the stage of *acceptance of difference* where the learner recognizes and appreciates cultural differences and responds with positive feelings, such as curiosity. In the next stage, *adaptation to difference*, the learner makes an asserted effort to take the perspective of others. Because of this new perspective-taking or "frame shifting" ability, the learner can more easily interact with people from other cultures. The final stage is *integration of difference*: the learner has internalized multiple cultural worldviews and can easily assume different perspectives. Integration is an advanced stage often requiring years of experience to achieve. In the context of the DMIS, the goal of intercultural training is to promote gradual movement through the stages and deliver appropriate training given the learner's progress. If, for example, behavioral change is rushed, the learner may develop an impoverished understanding of the new culture. As with learning in most domains, it is important to prevent shallow learning and to cultivate deep conceptual understanding.

Bennett's model is general, empirically grounded, and has produced a number of validated psychometric measures for assessment (Landis et al. 2004, pp. 85–128). However, a number of formulations of acculturation and intercultural learning also exist that are based on different theoretical foundations and serve different purposes. One example is the *ABC Model of Cultural Contact*, which focuses on development when one is immersed (physically) in a new culture (Ward et al. 2001). It integrates cultural learning (cognitive and behavioral), stress and adaptation, and social identity theory to explain how intercultural learning and growth occurs. Stress and adaption theory is considered because of the often stressful nature of learning about a new culture and the emotions that are typically encountered: learners naturally adopt coping strategies to handle cultural differences, feelings of superiority or inadequacy, and anger or feelings of loss. The theory suggests that the stress can be minimized through adaptive responses. Social identity theory provides a foundation for supporting learners in maintaining self-esteem given the new social groups in which they find themselves, and the natural biases they may encounter. In sum, Ward et al. (2001) seek to provide a comprehensive theory of acculturation and apply it to improve the effectiveness of intercultural training programs.

Finally, although researchers often decouple intercultural learning from language learning, compelling reasons exist to consider them together (Paige et al. 2000). Many of the features of spoken language, the way different languages enable achievement of communicative goals, and the history behind their evolution often relate closely to – or can be explained by – underlying cultural beliefs, values, and customs. Indeed, differences in spoken language represent a very noticeable difference for visitors to foreign cultures, and thus it is no surprise that language competence has the potential to dramatically ease intercultural learning by enabling more effective communication, question asking and answering, and so on. In addition, significant attention is paid by language education researchers to the differences between classroom learning and learning a language via immersion, and how this relates to intercultural learning. The fundamental idea of "context as culture" suggests that classroom-based instruction should seek to recreate cultural contexts for language learning (Paige et al. 2000). Given the increasing connectedness of the world, acquisition of language skills along with the general cognitive and metacognitive processes involved with intercultural competence will remain an important research topic for the unforeseeable future.

Important Scientific Research and Open Questions

Although specific models have proven useful to both explain intercultural learning and design effective intercultural training programs for certain contexts, significant open questions remain. For example, there is no general agreement on whether any existing theoretical model of intercultural learning is "sufficiently complex to capture all of the critical variables" or on how best to measure learning in a cultural context (Landis et al. 2004, p. 453). A recent meta-analytic review suggests that many training programs have been found to be effective at teaching cultural knowledge and generating learner satisfaction, but generally fall short in skill acquisition and attitude change. A possible explanation lies in the lack of strong, experiential components in the reviewed training programs – lectures, assimilators, discussion, and role-play are indicated as the top four types of programs (Landis et al. 2004, pp. 129–144). To address this shortcoming, a rapidly growing area of interest lies in the use of virtual learning environments and the use of virtual humans for cultural learning. Here, key open questions revolve around the validity and fidelity of such environments, both in terms of the computational models that drive interactions and their pedagogical design and integration into existing intercultural instruction (Ogan and Lane in press).

Cross-References

► Adaptation and Learning
► Anthropology of Learning and Cognitions
► Cross-Cultural Factors in Learning and Motivation
► Cross-Cultural Learning Styles
► Cross-Cultural Training
► Culture on Second Language Learning
► Emotions and Learning
► Transformational Learning

References

Bennett, M. J. (1993). Towards ethnorelativism: A developmental model of intercultural sensitivity. In R. M. Paige (Ed.), *Education for the intercultural experience* (2nd ed., pp. 21–71). Yarmouth: Intercultural Press.

Hall, E. T. (1959). *The silent language.* Garden City: Doubleday.

Landis, D., Bennett, J. M., & Bennett, M. J. (2004). *Handbook of intercultural training.* Thousand Oaks: Sage.

Ogan, A., & Lane, H. C. (in press). Virtual environments for culture and intercultural competence. In E. Blanchard & D. Allard (Eds.), *Handbook of research on culturally-aware information technology.* Hershey: IGI Global.

Paige, R. M., Jorstad, H., Siaya, S., Klein, F., & Colby, J. (2000). Culture learning in language education: A review of the literature. In R. M. Paige, D. L. Lange, & Y. A. Yershova (Eds.), *Culture as the core: Integrating culture into the language curriculum.* Minneapolis: University of Minnesota.

Ward, C. A., Bochner, S., & Furnham, A. (2001). *The psychology of culture shock.* Philadelphia: Routledge.

Intercultural Music Education

► International Perspectives in Music Instruction and Learning

Intercultural Sensitivity

► Developing Cross-cultural Competence

Intercultural Skill Acquisition

► Intercultural Learning

Intercultural Training

► Cross-cultural Training

Intercultural Transformation

► Intercultural Learning

Interdisciplinary Education

► Integrated, Multidisciplinary, and Technology-Enhanced Science Education

Interdisciplinary Research

► Multidisciplinary Research on Learning

Interest-Based Child Participation in Everyday Learning Activities

Carl J. Dunst, Melinda Raab
Orelena Hawks Puckett Institute, Asheville, NC, USA

Synonyms

Circumscribed interests; Curiosity; Intense interests; Personal interests; Perseverative interests; Situational interests

Definition

The word *interest* when used by educators and psychologists refers to the characteristics of a person, object, or event that engages a person in sustained interaction with objects or others. Interests include a person's likes, preferences, favorites, affinity toward, or attraction to a subject, topic, or activity. Displays of interests typically include enjoyment, pleasure, and satisfaction as well as *emotional involvement* in a task or activity.

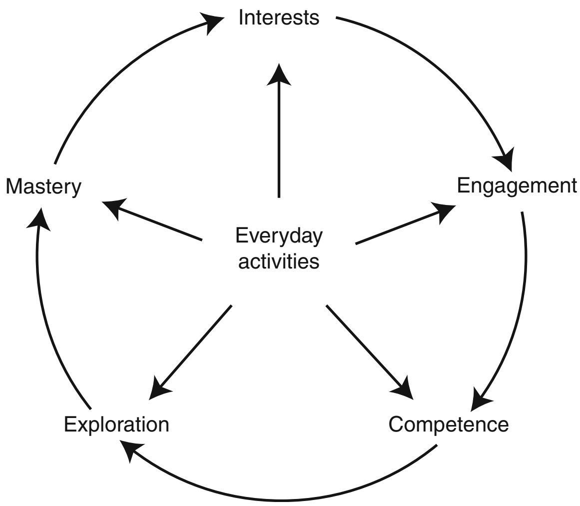
More than 100 years ago, John Dewey in his book, *The School and Society* (1899), noted that children's natural curiosities such as "interest in conversation, or communication; in inquiry or finding out things; in making things, or construction; and in artistic expression [are the] natural resources, the uninvested capital, upon which depends the active growth of the child" (pp. 47–48). Dewey's description captures the key features of *interest-based child learning*; namely, active child participation in everyday activities that are either contexts for interest expression or are interesting to a child, and which provide opportunities for situated learning (Göncü 1999).

Theoretical Background

Interests have played a central role in theories of child learning and development for more than a century (see Silvia 2006). Theorists have described different types of interests in different ways. Krapp, Hidi, and Renninger (1992) differentiate between *personal* and *situational* interests and describe how both types of interests are related to one another. ► Personal interests are the characteristics of a person that influence his or her engagement in interactions with the social or nonsocial environment. ► Situational interests refer to the interestingness of the social or nonsocial environment that evoke or encourage interactions with people or objects. The influences of both types of interests are bidirectional, transactional, and mutually reinforcing. The consequences of participation in interest-based activity include, but are not limited to, improved competence, increased motivation, and personal well-being.

Infants as young as 2 or 3 months of age demonstrate personal interests as well as interest in their surroundings. Their interests are manifested in terms of their preferences for certain positions, sounds, and sights; prolonged attention to people, objects, and events; and emotional expression. Interests are often accompanied by laughter, excitement, and intense engagement in activity and play. Both *contingency detection and awareness* appear to play important roles in how interests are reinforced by child engagement in everyday activity (Dunst et al. 2008).

Child development theory and research on interests, engagement, exploration, and mastery motivation were used to develop the model shown in Fig. 1 (Dunst 2006). *Everyday activities* that children experience as part of family and community life are viewed as sources of situationally interesting social and nonsocial events and the contexts for personal interest expression. According to the model, interest-based child participation in everyday activity provides the context for



Interest-Based Child Participation in Everyday Learning Activities. Fig. 1 Model for depicting the key features of interest-based everyday child learning

sustained *engagement* in interactions with people and material. Sustained engagement in turn provides a child the opportunity to practice *existing competence* and learn *new behavior*. As part of competence expression and learning, a child has an opportunity to *explore* the consequences of his or her abilities and to develop a sense of *mastery*. A sense of mastery in turn is likely to strengthen personal interests and transform situationally interesting everyday activity into personal interests.

The model shown in Fig. 1 and the relationships between the elements in the model were the foundations to an approach to early childhood intervention that identifies both children's interests and the everyday activities that are contexts for interest-based learning where learning is facilitated by parents and other caregivers increasing child participation in the activities (Dunst 2006). The benefits include, but are not limited to, improved child and parent competence and confidence.

Important Scientific Research and Open Questions

Research and practice on young children's interests pose several challenges that are not major issues in studies of older children and adults. Whereas the difference between personal and situational interests is relatively easy to conceptualize and operationalize in studies of older children and adults, the differences are not as clear in studies of younger children and especially infants and toddlers. The ways in which situational interests become personal interests among young children is another area where research is needed.

There is a need for better designed measures of young children's interests. Most approaches rely on parents' reports. Observations of young children's interactions with their social and nonsocial environment show clear preferences for certain material or activity. An observational measure of young children's interests may therefore be of potential value in studies of interests and interest-based learning. Comparative studies using different assessment methods could prove important in terms of which methods best capture children's interests. These types of studies could include concomitant measures of child engagement, behavior competence, exploration, and mastery to determine which types of interest assessment methods best explain variations in those concomitant measures.

There are a number of challenges related to promoting professionals' and parents' use of interest-based everyday learning activities to promote child development, and especially with young children with delays or disabilities. Most planned interventions implemented by professionals or prescribed to parents by professionals are predominately adult-directed. In contrast, interest-based child learning is mostly child-directed. In those cases where child interests are incorporated into child-learning activities, adults use mostly situational interests to entice or evoke child engagement (e.g., introducing attractive toys to a child). Personal interests are rarely used to decide which kinds of everyday activity are best suited for child learning despite the fact that personal interests are more important determinants of child behavior and skill acquisition (Raab and Dunst 2007). Both research and everyday experiences "tell us" that people in general and young children more specifically become increasingly proficient in their performance when engaged in activities that are personally interesting.

Another area of important research and practice with young children is a better understanding of how personal and situational interests influence one another, and how they have independent, interactive, and mediating effects on child learning and development. Studies of young children that include measures of both types of interests could be highly informative.

Cross-References

▶ Curiosity and Exploration
▶ Dewey, John (1858–1952)
▶ Everyday Learning Instruction and Technology Designs
▶ Informal Learning
▶ Interests and Learning
▶ Learning in Informal Settings
▶ Situated Learning

References

Dewey, J. (1899). *The school and society.* Chicago, IL: University of Chicago Press.
Dunst, C. J. (2006). Parent-mediated everyday child learning opportunities: I. Foundations and operationalization. *CASEinPoint, 2*(2), 1–10. http://www.fippcase.org/caseinpoint/caseinpoint_vol2_no2.pdf.
Dunst, C. J., Trivette, C. M., Raab, M., & Masiello, T. (2008). Early child contingency learning and detection: Research evidence and implications for practice. *Exceptionality, 16*, 4–17.
Göncü, A. (Ed.). (1999). *Children's engagement in the world: Sociocultural perspectives.* Cambridge: Cambridge University Press.
Krapp, A., Hidi, S., & Renninger, K. (1992). Interest, learning and development. In K. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 3–25). Hillsdale: Erlbaum.
Raab, M., & Dunst, C. J. (2007). *Influence of child interests on variations in child behavior and functioning* (Winterberry research syntheses, Vol. 1). Asheville: Winterberry Press (No. 21).
Silvia, P. J. (2006). *Exploring the psychology of interest.* New York: Oxford University Press.

Interests and Learning

Ulrich Schiefele
Department of Psychology, University of Potsdam, Potsdam, Germany

Synonyms

Attentiveness to learning; Pursuit of learning

Definition

Two different forms of interest are distinguished in the literature: situational and individual interest (cf. Hidi et al. 2004; Schiefele 2009). *Situational interest* is a temporary emotional state aroused by specific features of a situation, task, or object (e.g., vividness of a text passage). It involves focused attention, increased cognitive functioning, persistence, enjoyment or affective involvement, and curiosity (Hidi et al. 2004; Renninger 2000; Silvia 2006). In addition, when interest is high, focusing attention and cognitive activity feel relatively effortless. According to Hidi (1995), automatic attention may explain the beneficial effect of interest on cognitive functioning.

Individual interest is conceptualized as a relatively stable affective-evaluative orientation toward certain subject areas or objects (e.g., Hidi et al. 2004; Krapp 1999; Schiefele 2009). More specifically, individual interest is defined as a relatively stable set of *valence beliefs* (Schiefele 1996, 2009). Valence beliefs denote cognitively represented relations between a domain (e.g., physics) and evaluative attributes. These attributes may be either feeling- or value- related. Feeling-related attributes refer to feelings that are associated with a domain (e.g., excitement, stimulation, and flow), whereas value-related attributes refer to the personal significance of a domain (e.g., if the domain helps to realize one's self or is central to one's self-concept).

Theoretical Background

Interests and Text Learning

The greatest amount of research on the relation between interest and learning refers to learning from text. Given the long tradition of that research and the multitude of studies (cf. Schiefele 1996, 1999), it seems obvious that interest has been considered to be a major motivational condition of text learning (see also Alexander et al. 1994).

Prior studies have either investigated the effects of *interestingness* of text materials (as an indicator of situational interest) or *topic interest* (as an indicator of individual interest) on text learning (cf. Schiefele 1996, 1999). In studies on situational interest, subjects usually were asked to rate the interestingness of text segments (sentences or paragraphs). In most cases, intraindividual comparisons between lowly and highly interesting sentences were performed. In order to measure topic interest, respondents had to rate their level of interest in the text topic before reading the text.

Situational Interest and Text Learning

Schiefele (1996) analyzed 14 relevant studies and found an average correlation of 0.33 between situational

I

interest and text learning (see also Alexander and Jetton 1996). The findings suggested that the relation between situational interest and text learning is independent of factors such as text length, readability, importance of text or text segments, unit of analysis (sentence vs. passage vs. whole text), nature of text (narrative vs. expository), method of learning test (e.g., recognition vs. recall), age (or grade level), and reading ability (or intelligence).

In a recent study, Guthrie et al. (2006) compared four classes with high versus low numbers of stimulating tasks that were designed to increase situational interest. All four classes were part of an intervention program (Concept-Oriented Reading Instruction) in which teachers linked reading fiction and nonfiction books to science activities. The number of stimulating hands-on science activities varied between classes. This enabled the authors to select two classes with high numbers and two classes with low numbers of interesting activities. A comparison between the students in the two types of classes not only revealed differences in students' intrinsic reading motivation, but also in their reading comprehension. Students in the two classes with high numbers of stimulating activities exhibited significantly higher means in a standardized reading comprehension test than the students in the other two classes.

Topic Interest and Text Learning

In the above-mentioned meta-analysis (Schiefele 1996), an average correlation of 0.27 between topic interest and text learning was found based on a total of 22 studies. Furthermore, the findings suggested that the relation between topic interest and text learning is not affected by factors such as text length, nature of text, method of learning test, age (or grade level), reading ability, and text difficulty. In addition, the reviewed studies support the conclusion that interest and prior knowledge do have independent effects on text learning. However, the effects of prior knowledge were stronger than those of topic interest. Usually, only low to moderate correlations between topic interest and prior knowledge were found.

There is some evidence that topic interest better predicts indicators of deep-level than of surface-level learning. For example, Groff (1962) was able to show that topic interest was more strongly related to outcomes from a multiple-choice test referring to text organization, inferences, and conclusions than to outcomes from a multiple-choice test referring to explicit details in the text. In accordance with these findings, Kunz et al. (1992) found higher correlations between topic interest and performance at an application task (transfer of text content to a concrete example) than between interest and standard indicators of text learning (free recall and multiple-choice comprehension questions). Both studies reported higher correlations for prior knowledge and ability factors than for interest with respect to all indicators of text learning. In two of our own studies (Schiefele 1990; Schiefele and Krapp 1996), it was found that topic interest was most highly related to outcome measures indicating deep levels of learning, such as deep comprehension, recall of main ideas, elaborations, and coherence of recall of main ideas. The associations between topic interest and other indicators of learning were lower or not significant. In addition, all the relations between topic interest and learning were independent of prior knowledge and cognitive ability.

The stronger associations between interest and deep-level text learning as opposed to surface-level text learning may be explained by two assumptions: (1) deep-level indicators require more cognitive effort than surface-level measures and (2) interested readers are more willing than less interested readers to invest effort in order to answer challenging and complex questions.

Andre and Windschitl (2003) reported a number of studies that were aimed at facilitating the understanding of electric current flow. In these studies, college students received either a conceptual change text (designed to challenge alternative conceptions and promote conceptual change) or a regular science text. Across various studies, conceptual change texts led to superior conceptual understanding. The authors also assessed students' interest and prior experience with physics and electricity, as well as their verbal ability. By means of multiple regression analyses, a significant relation between interest and conceptual understanding was revealed. That relation proved to be independent of text type, gender, verbal ability, and prior experience. Moreover, interest was found to affect posttest understanding even when a measure of pretest understanding was taken into account. In line with earlier findings, Andre and Windschitl (2003) were able to demonstrate significant effects of interest on conceptual understanding that were independent of ability and prior knowledge. As an explanation of the effects of interest on conceptual change, the authors argued that interest facilitates the degree of involvement that leads to deeper processing.

Important Scientific Research and Open Questions

Interests, School Achievement, and Academic Choices

There is ample evidence that individual or subject matter interest and school achievement (grades, standardized tests) are positively correlated. In a review of relevant research, Schiefele et al. (1992) reported that on average the strength of subject area interest accounts for about 10% of observed achievement variance. Both grade level and nature of subject area did not influence that relation. However, it was found that male students' achievement is more strongly associated with their interest level than was the case for female students. Schiefele et al. (1992) concluded that the strength and causal nature of the interest–achievement relation cannot be definitively determined unless other relevant predictors are taken into account and unless longitudinal data are available. For example, most of the reviewed studies did not include indicators of cognitive ability or prior achievement. Earlier studies, however, suggest that interest and ability are not strongly interrelated and contribute independently of each other to the prediction of achievement (cf. Schiefele et al. 1992).

Another unresolved issue pertains to the causal relation between interest and achievement. On the one hand, it may be argued that the perception of successful performance leads to positive affect and enhanced interest. On the other hand, interest may contribute to high levels of achievement because it facilitates effort, elaborative processes, and strategy use (e.g., McWhaw and Abrami 2001). In a more recent longitudinal study, Köller et al. (2001) were able to show that a reciprocal relation between interest and achievement is likely. A large sample of students from academically selected schools ("Gymnasium") in Germany was tested at three time points: end of Grade 7, end of Grade 10, and middle of Grade 12. The focus of measurement was on interest and achievement in mathematics (as measured by a standardized test based on items from the TIMSS study). In the German Gymnasium, students have the opportunity at the end of Grade 10 to choose either a basic or an advanced mathematics course. Structural equation analyses showed that interest in Grade 7 had no significant effects on achievement in either Grade 10 or 12. In contrast, achievement at the end of Grade 7 did significantly affect interest in Grade 10. High achievers expressed more interest in mathematics than low achievers. There were, however, significant direct and indirect effects of Grade 10 interest on Grade 12 achievement, although Grade 10 achievement was taken into account. The indirect effect of interest was mediated by *course selection*: Highly interested students were more likely to choose an advanced course. Course selection, in turn, affected Grade 12 achievement significantly.

The findings from this study, as well as those from other studies (see Baumert and Köller 1998; Marsh et al. 2005), suggest that at least at the lower secondary school level interest is either a nonsignificant or weak antecedent of achievement. Köller et al. (2001) argue that in German lower secondary schools students' motivation is mostly regulated by extrinsic incentives and values (e.g., regular written tests, parental reinforcements). Consequently, interest only plays a marginal role in initiating and maintaining academic activities. In upper secondary school classes, the frequency of written examination and, thus, the impact of extrinsic incentives decrease. Therefore, interest is gaining more influence on the regulation of learning activities.

Concluding Comments

The present chapter reviewed the role of interest in learning. There is relatively strong evidence for a substantive relation between both situational and individual interest and indicators of learning, particularly with respect to text learning. Although interest effects on learning are on the average only of small or medium size, it is noteworthy that interest effects are even observable when relevant cognitive variables are taken into account. Despite these positive findings, there is a need for more experimental research, for further clarifying the relation between interest and different learning indicators within more complex models, and for identifying relevant mediator variables.

A particularly interesting and important finding refers to the impact of interest on academic choices. Köller et al. (2001) suggested that interest becomes more influential if students are allowed to self-regulate their learning activities to a larger degree.

This influence becomes even larger when students have choices, such as the choice between regular and advanced courses (see also Wigfield and Eccles 2000). It follows that an important task for future research would be to further substantiate Köller et al.'s proposition that choice and self-regulation enhance the importance of (individual) interests (see also Deci 1998).

Cross-References

► Academic Motivation
► Curiosity and Exploration
► Interest-Based Child Participation in Everyday Learning
► Learning from Text
► Motivation to Learn: Modern Theories
► Motivation, Volition and Performance
► Multifaceted Nature of Intrinsic Motivation
► Stability and Change in Interest Development

References

Alexander, P. A., & Jetton, T. L. (1996). The role of importance and interest in the processing of text. *Educational Psychology Review, 8*, 89–121.

Alexander, P. A., Kulikowich, J. M., & Jetton, T. L. (1994). The role of subject-matter knowledge and interest in the processing of linear and nonlinear texts. *Review of Educational Research, 64*, 201–252.

Andre, T., & Windschitl, M. (2003). Interest, epistemological belief, and intentional conceptual change. In G. M. Sinatra & P. R. Pintrich (Eds.), *Intentional conceptual change* (pp. 173–197). Mahwah: Erlbaum.

Baumert, J., & Köller, O. (1998). Interest research in secondary level I: An overview. In L. Hoffmann, A. Krapp, K. A. Renninger, & J. Baumert (Eds.), *Interest and learning* (pp. 241–156). Kiel: Institute for Science Education.

Deci, E. L. (1998). The relation of interest to motivation and human needs – The self-determination theory viewpoint. In L. Hoffmann, A. Krapp, K. A. Renninger, & J. Baumert (Eds.), *Interest and learning* (pp. 146–162). Kiel: Institute for Science Education.

Groff, P. J. (1962). Children's attitudes toward reading and their critical reading abilities in four content-type materials. *Journal of Educational Research, 55*, 313–317.

Guthrie, J. T., Wigfield, A., Humenick, N. M., Perencevich, K. C., Taboada, A., & Barbosa, P. (2006). Influences of stimulating tasks on reading motivation and comprehension. *Journal of Educational Research, 99*, 232–245.

Hidi, S. (1995). A reexamination of the role of attention in learning from text. *Educational Psychology Review, 7*, 323–350.

Hidi, S., Renninger, K. A., & Krapp, A. (2004). Interest, a motivational variable that combines affective and cognitive functioning. In D. Y. Dai & R. J. Sternberg (Eds.), *Motivation, emotion, and cognition* (pp. 89–115). Mahwah: Erlbaum.

Köller, O., Baumert, J., & Schnabel, K. U. (2001). Does interest matter? The relationship between academic interest and achievement in mathematics. *Journal of Research in Mathematics Education, 32*, 448–470.

Krapp, A. (1999). Interest, motivation and learning: An educational-psychological perspective. *European Journal of Psychology of Education, 14*, 23–40.

Kunz, G. C., Drewniak, U., Hatalak, A., & Schön, A. (1992). Zur differentiellen Bedeutung kognitiver, metakognitiver und motivationaler Variablen für das effektive Lernen mit Instruktionstexten und Bildern [The differential role of cognitive, metacognitive, and motivational factors for effective learning with instructional texts and pictures]. In H. Mandl & H. F. Friedrich (Eds.), *Lern- und Denkstrategien* (pp. 213–229). Göttingen: Hogrefe.

Marsh, H. W., Trautwein, U., Lüdtke, O., Köller, O., & Baumert, J. (2005). Academic self-concept, interest, grades, and standardized test scores: Reciprocal effects models of causal ordering. *Child Development, 76*, 397–416.

McWhaw, K., & Abrami, P. C. (2001). Student goal orientation and interest: Effects on students' use of self-regulated learning strategies. *Contemporary Educational Psychology, 26*, 311–329.

Renninger, K. A. (2000). Individual interest and its implications for understanding intrinsic motivation. In C. Sansone & J. M. Harackiewicz (Eds.), *Intrinsic and extrinsic motivation* (pp. 373–404). San Diego: Academic.

Schiefele, U. (1990). The influence of topic interest, prior knowledge and cognitive capabilities on text comprehension. In J. M. Pieters, K. Breuer, & P. R. J. Simons (Eds.), *Learning environments* (pp. 323–338). Berlin: Springer.

Schiefele, U. (1996). *Motivation und Lernen mit Texten [Motivation and text learning]*. Göttingen: Hogrefe.

Schiefele, U. (1999). Interest and learning from text. *Scientific Studies of Reading, 3*, 257–279.

Schiefele, U. (2009). Situational and individual interest. In K. R. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 197–222). New York/London: Routledge.

Schiefele, U., & Krapp, A. (1996). Topic interest and free recall of expository text. *Learning and Individual Differences, 8*, 141–160.

Schiefele, U., Krapp, A., & Winteler, A. (1992). Interest as a predictor of academic achievement: A meta-analysis of research. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 183–212). Hillsdale: Erlbaum.

Silvia, P. J. (2006). *Exploring the psychology of interest*. New York: Oxford University Press.

Wigfield, A., & Eccles, J. S. (2000). Expectancy-value theory of achievement motivation. *Contemporary Educational Psychology, 25*, 68–81.

Interference

The disruption of the memory of an event as a result of conflicting information that was acquired either before (*proactive interference*) or after (*retroactive interference*) it.

Interference Effect

Empirical violations of the law of total probability are termed interference effects. These effects can be found both in physical systems and human cognitive systems. Quantum theory was initially invented to explain these effects in particle physics. Psychologists have also found interference effects in humans, motivating researchers to apply quantum theory to cognitive science.

Intergenerational Learning

The learning that happens naturally in the home between parents and children and includes the wider family and community. This can also be a two-way process with children passing on new skills to older generations.

Interiorization

► Internalization

Interlanguage

The term commonly used in second language research since the 1970s to refer to the language learner's evolving target language system.

Internal Balance

► Physiological Homeostasis and Learning

Internal Model

► Mental Models

Internal Reinforcement

► Internal Reinforcement Hypothesis

Internal Reinforcement Hypothesis

Dorothea Eisenhardt, Randolf Menzel
Department of Biology/Chemistry/Pharmacy, Institut für Biologie - Neurobiologie, Freie Universität Berlin, Berlin, Germany

I

Synonyms

Associative learning; Extinction learning; Internal reinforcement; Reconsolidation; Reinforcement learning

Definition

The internal reinforcement hypothesis proposes that in retrieving a consolidated memory, two forms of learning take place, one based on the lack of external reinforcement (extinction learning) and one based on the internal existence of reinforcement (reminder learning). The internal reinforcement hypothesis offers an interpretation for the phenomenon of spontaneous recovery based on the properties of the reward system activated by appetitive stimuli and may capture properties of reconsolidation (Eisenhardt and Menzel 2007).

Theoretical Background

In classical conditioning, an animal learns that a previous neutral stimulus (conditioned stimulus, CS) is associated with an unconditioned stimulus (US). As a consequence, a conditioned response (CR) is elicited by the CS when presented without the US. Repeated presentations of the unreinforced conditioned stimulus (CS) lead to a decrease of the CR. This decrease of the CR is termed extinction. Extinction is based on new learning that leads to an extinction memory that undergoes a protein synthesis-dependent consolidation process. Many studies demonstrate that after extinction the CR reappears. This phenomenon is termed spontaneous recovery. Possibly, consolidation of extinction memory and the memory underlying spontaneous recovery are two parallel processes, and the behavioral outcomes resemble a balance between two memory traces at a certain time after memory retrieval. Consolidation underlying spontaneous recovery could be related to reconsolidation, a process that is thought to make already consolidated memory susceptible to interference like protein synthesis inhibition.

Important Scientific Research and Open Questions

The reminder memory is proposed to form based on the properties of reinforcing neurons in monkeys and honeybees (Schulz 2006, Hammer 1993). Accordingly, the internal reinforcement hypothesis can be tested by studying the properties of the reinforcement neurons in different model systems and, thus the mechanisms of spontaneous recovery and reconsolidation.

Cross-References

► Memory consolidation and reconsolidation
► Reinforcement learning in animals

References

Eisenhardt, D., & Menzel, R. (2007). Extinction learning, reconsolidation and the internal reinforcement hypothesis. *Neurobioogy of Learning and Memory, 87*, 167–173.

Hammer, M. (1993). An identified neuron mediates the unconditioned stimulus in associative olfactorylearning in honeybees. *Nature, 366*, 59–64.

Nader, K., & Hardt, O. (2009). A single standard for memory: the case for reconsolidation. *Nat Review of Neuroscience, 10*(3), 224–234.

Schultz, W. (2006). Behavioral theories and the neurophysiology of reward. *Annual Review of Psychology, 57*, 87–115.

Internal Representation

► Knowledge Representation
► Mental Representations

Internal Representation of Beliefs and Ideas of Environmental Problems

► Mental Models of Environmental Problems

Internality

► DICK Continuum in Organizational Learning Framework

Internalization

Andrey Podolskiy
Department of Developmental Psychology,
Moscow State University, Moscow, Russia

Synonyms

Acquisition; Appropriation; Assimilation; Interiorization; Mastering; Transformation

Definition

The term *internalization* is used in various disciplines, such as the social sciences, the humanities, and even biology and economics, to designate the process of transformation (reflection, transition) of external events, processes, and appearances into internal ones. The concept of internalization has a long history, in the course of which it has changed its content and status many times. The internalization idea has been applied to fields such as psychoanalysis and sociological schools, genetic epistemology and cultural-historic theory, to name but a few. As it first appeared as a vivid metaphor and has attracted continuous attention from scholars for many decades, it is no wonder that different authors (including such prominent figures as Aronfreed 1968; Baldwin 1911; Bandura 1986; Freud 1937; Janet 1935; Piaget 1974; et al.) have suggested different meanings for the term. For instance, one may compare the meanings of *internalization* as an appropriation of collective representations by individuals in the works of Durkheim and Lévy-Bruhl to the concept of the psychological process of *introjection*, a psychological defense mechanism, in Freudian psychoanalysis.

Theoretical Background

The concept of *internalization* is one of the main milestones in the *cultural-historical theory of development*. Soviet/Russian psychologist Lev Vygotsky (1896–1934), the founder of cultural-historical theory, considered the process of *internalization* as the incorporation of cultural tools into the subject's mental processes. The process of mediation represents the major and crucial difference between human and animal mental activity: As a result of cultural mediation, human mental activity becomes (or at least can become) voluntary. Vygotsky introduced the notion of the *higher mental functions* as opposed to the elementary (natural) mental functions. Unlike the elementary (natural) mental functions, the higher mental functions are not inborn but rather are the product of social and historical development; their occurrence is determined by the features of human life. Signs and meanings mediating the higher mental functions are psychological tools for human mental activity which are functionally similar to labor tools. Logical thinking, voluntary memory, and voluntary attention may be considered as examples of the higher mental functions, while verbal meanings, math signs, mnemonic techniques, etc., serve as psychological tools. The higher mental functions are characterized by their "double sociality" – by structure (mediated by social signs and meaning) and by origin (occurring only in the process of communication) (Vygotsky 1978). Vygotsky formulated what he called a "general genetic law of cultural development" declaring that any function in the child's cultural development appears twice, or on two planes. First, it appears between people as an interpsychological category, and then within the child as an intrapsychological category. It is important to emphasize that Vygotsky's approach rejects both the assumption that the structures of external and internal activities are identical and the assumption that they are unrelated (Wertsch 1985). Another important point is that internalization represents a complex transformational process and not a simple transition from "inter-" to "intra-"; accordingly, "the relationship between external and internal functioning is one involving genetic transformations rather an identical replica" (Wertsch 1985, p. 66).

In the works of Leontiev and his close collaborators (Davydow, Elkonin, Zaporozhets, P. Zinchenko, V. Zinchenko et al.), another emphasis has appeared. These authors speak not only of internalization with respect to the mediated structure of social interaction but also and mainly to characterize the transformation of external object-related meaningful activity into internal, mental forms of activity (Leontiev 1981; Arievitsch and Van der Veer 1995). Leontiev postulates that "the process of internalization is not the transferal of an external activity to a preexisting, internal "plane of consciousness": it is the process in which the internal plane is formed (Leontiev 1981, p. 163). Thus, in spite of their mutual cultural-historic background, it is possible to distinguish two basic dimensions of internalization: the dimension of internalization "from social to individual," one of Vygotsky's main concerns, and the dimension of internalization "from external to internal," representing the angle of consideration taken by Leontiev and his collaborators. It is important to emphasize that these two dimensions do not contradict but rather complement each other: The first dimension "from social to individual" establishes a general megaconceptual space inside of which the second dimension "from external to internal" describes a macrodevelopmental strategy explaining the process and results of the emergence of new psychological formations during one's lifespan.

Important Scientific Research and Open Questions

In considering the psychological literature of the past few decades, one can notice a kind of "wavy" trend in both the number of theoretical or experimental papers on the problem of internalization and the authors' expectations presented in them. It seems that scientific interest in the problem rises whenever scholars discover new facets, new potentialities of the "internalization approach" and falls again when it becomes apparent that there are limited possibilities for operationalizing the internalization ideas and making the crucial step from a vivid metaphor to a sufficiently concrete description of complex transformations of initially external (social, materialized) forms of human activity into internal (ideal, mental) forms.

These "waves" are noticeable in the Western as well as the Soviet/Russian psychological literature. The points of the most heated and frequent discussions revolve around questions like: What is internalized? What is the psychological content of the concepts "external" and "internal"? What are the "rules" of applying the knowledge of internalization to psychological and educational practice?

Most of these questions are answered in a more or less detailed and operationalized way in the psychological doctrine of Russian psychologist Piotr Galperin (1902–1988). Galperin's approach is the continuation of a trend in developmental and learning psychology started by Vygotsky. However, Galperin's approach introduces the following new elements: (1) The approach considers the nature of human mental life, its coming into existence, and its further development in the context of philogenetical, anthropogenetical, and ontogenetic processes, and (2) it considers the system of psychological conditions, which enables mental actions, images, and representation formation with the desired and prescribed outcomes. According to Galperin, mental action as a unit of analysis of object-related, meaningful human activity is a functional structure that is formed continually throughout an individual's lifetime. Using mental actions, mental images, and representations, a human being plans, regulates, and controls his/her performances by means of socially established patterns, standards, and evaluations. Mental action can and should be considered as the result of a complex, multimodal transformation of initially external processes performed by means of certain tools. In other words, from a nomothetic point of view, concrete mental actions, images, and representations are the result of the *internalization* of external processes (Galperin 1989).

Galperin introduced *six stages of internalization* as the fundamental basis of any learning process: (1) formation of a motivation base of action; (2) formation of an orientation base of action; (3) formation of the material (materialized) form of action; (4) formation of the external socialized verbal form of action (overt speech); (5) formation of the internal verbal form of action (covert speech); (6) formation of the mental action, final changes, automatization, and synchronization of the action (Galperin 1992).

Internalization is considered to be one line which together with three others is described by Galperin as a system of psychological conditions that ensure and guarantee the achievement of prescribed, desired properties of action and image; this system is termed the "system of planned, stage-by-stage formation of mental actions" or the *PSFMA system*. The PSFMA system includes *four subsystems:*

(1) the conditions that ensure adequate motivation for the subject's mastering of the action; (2) the conditions that provide the formation of the necessary orientation base of action; (3) the conditions that support the consecutive transformations of the intermediate forms of action (materialized, verbal), and the final transformation into the mental plan, or the conditions of the *internalization*; and (4) the conditions for cultivating or "refining through practice" the desired properties of an action (Galperin 1989). Each subsystem contains a detailed description of related psychological conditions, including the motivational and operational areas of human activity.

The *first* subsystem (conditions for motivation) makes explicit a number of links and connections between learning motivation and the dynamics of the internalization processes.

The *second* subsystem (conditions for orientation) contains a description of hierarchically organized components, which together offer a framework for the formation of a concrete action and provide a learner with the conditions for adequate ("complete" according to Galperin) orientation within a problem situation. These components are the representations of the subjective and objective characteristics of a problem situation and were termed by Galperin collectively as the "complete orientation base of action" (Galperin 1992).

The third subsystem represents the stages of internalization or transformation of the action into a mental plan (see above).

The *fourth* and last subsystem contains a description of the three base problem situation types and how they are combined and presented during the formation processes. Three basic types are distinguished: (1) the "psychological" type, in which the conceptual and perceptual or visible features of a problem situation are opposed; (2) the "logical" type, in which necessary and essential parameters are contrasted with unnecessary or "noisy" parameters of a problem situation; and (3) the "object" type, in which all of the possible forms of a specific action object content are varied. Different problem types are offered in a sequence which is meaningful for learners (Galperin 1989).

It is possible to speak about the internalization process in a broad sense as a systemically organized multidimensional transformation of human action and also, in a narrow sense, when one is considering only one line of this transformation, namely the change in the form of the developing action – from external (material, materialized) via verbal to internal (mental, ideal).

Certainly, there are several open questions on this issue. One of the most complex and penetrating problems is that of the interrelations between an internal process of internalization and an external system of conditions under which a process appears and develops. One should not forget that the researcher or teacher actually has to deal not only with an action but with an individual who is a human being endowed with certain attitudes toward the experiment, the researcher, the material the latter uses, etc. Therefore, in completing the assignment in the process of the experimentation, the subject is solving not only the task assigned but also a whole set of other psychological tasks. It may be suggested that even in cases in which we obtain the supposed action (new competency) with all required properties as a result of planned formative procedure, the properties as well as the process of their acquisition may (and in the long run must) be viewed in a broader context in the light of the totality of the subject's attitudes toward the experimental situation (taking into account his or her age and individual peculiarities). But then how should we draw the contours of concrete experimental research? What is possible and what is impossible to leave behind in the model of experimental situation while studying internalization processes?

Cross-References

► Activity Theories of Learning
► Cultural-Historical Theory of Development
► Learning Activity
► Mental Activities of Learning
► Zone of Proximal Development

References

Arievitsch, I., & Van der Veer, R. (1995). Furthering the internalization debate: Gal'perin contribution. *Human Development, 36*, 113–126.

Galperin, P. I. (1989). Organization of mental activity and effectiveness of learning. *Journal of Soviet Psychology, 27*(3), 65–82.

Galperin, P. I. (1992). Stage-by-stage formation as a method of psychological investigation. *Journal of Russian and East European Psychology, 30*(4), 60–80.

Leontiev, A. N. (1981). *Problems of the development of mind*. Moscow: Progress.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: MIT Press.

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind*. Cambridge, MA: Harvard University Press.

International Music Education

► International Perspectives in Music Instruction and Learning

International Perspectives in Music Instruction and Learning

C. Victor Fung, Patrick Hernly
Center for Music Education Research, School of Music, MUS 101, College of The Arts, University of South Florida, Tampa, FL, USA

I

Synonyms

Comparative music education; Intercultural music education; International music education; World music education

Definition

International perspectives in music instruction and learning offer insights in the study of issues in music education across national boundaries. In each nation, there are activities in music instruction and learning within a social structure and a set of political ideologies, educational policies, cultural values, and musical traditions. These perspectives represent the views in music instruction and learning that take place in various geopolitical and sociocultural contexts. They encourage an international and cross-cultural understanding, examination, and borrowing of music education practices. They also encourage the development of and access to music education in societies throughout the world.

Theoretical Background

Sporadic exchange of ideas in music instruction and learning has occurred between nations prior to the twentieth century, but such exchange has exploded in the twentieth century and has continued into the twenty-first century. This explosion of exchanges could be attributed to four major events that occurred in the twentieth century: transformation of the field from comparative musicology to ethnomusicology, development of comparative education and comparative music education, establishment of the United

Nations and its subsidiaries in music, and the increased impact of media and technology worldwide.

Comparative Musicology to Ethnomusicology

Early scholars interested in studying music of non-Western cultures represented a branch of musicology known as "comparative musicology," a term that was used from approximately 1885 through the 1950s. Guido Adler was acknowledged as adding the adjective "comparative" to the term "musicology" in an 1885 publication to describe the work of scholars such as Alexander John Ellis, who compared musical scales cross-culturally in the mid-1880s, setting the term into use among musicologists. Though criticism of the term "comparative musicology" arose as early as 1905, later scholars strongly argued against its use (Haydon 1941) on the grounds that scholarship in the field did not engage in scientific comparison as in other scientific areas of inquiry.

Jaap Kunst first wrote about "ethnomusicology" in 1950, reinforcing the important link between musicology and ethnography in the study of music in culture. Throughout the latter 1950s, "comparative musicology" and "ethnomusicology" were used side by side (Merriam 1977). In 1954 Bruno Nettl used the hyphenated form "ethno-musicology" to describe course offerings related to the field in colleges and universities. In 1955, however, Nettl provided for musicologists a bibliography of musicological articles published in anthropological journals, and did not use the term "ethnomusicology" once in the document, using "comparative musicology" instead. Mieczyslaw Kolinsky noted the parallel use of both terms in a 1957 article in which he suggested that "ethnomusicology" was the preferable term, and that "comparative musicology" was insufficient because the field included descriptive research of non-Western musics as well as comparative studies. The establishment of the Society for Ethnomusicology in the USA in 1955 further strengthened the consensus of the "ethnomusicology" identity in the field. By the early 1960s, "comparative musicology" had fallen almost completely out of current use, and "ethnomusicology," with its emphasis on seeking to understand each system of music in its own cultural context rather than engaging in relatively superficial cross-cultural comparisons, won out. A major subtext of this change was to eliminate the notion that all musical traditions should be compared against the Western-art music tradition or any other tradition. It confirmed the value of each musical tradition in its own rights.

Comparative Education and Comparative Music Education

Although exchange of ideas in education across nations has occurred prior to the twentieth century, comparative education was not an established field until the 1930s as Isaac L. Kandel (1881–1965) published his seminal book *Comparative Education* in 1933. Comparative education is a field that studies educational issues, data, situations, systems, or solutions from one country and compared them against another country. Scholars in this field believe that finding common principles across national contexts could contribute to the advancement of education. Studying aspects of education from another nation could help to understand the educational scheme of one's own nation. These principles are valuable to some music education scholars, such as Cykler (1961) and Kemp and Lepherd (1992). However, according to Kertz-Welzel (2008), comparative music education is still an emerging field with much to learn from comparative education in methodology and epistemology. It is easy to observe that the music education research literature has an increasing body of research that includes comparative data across national boundaries in the last few decades, but comparative music education is still not widely recognized as a field of study. Regardless of the status of comparative music education as a field of study, it is clear that music education researchers are aware of the need to expand on their international perspectives.

Media and Technology

Transmission of music cross-culturally has increased with the development of the media and technology. Beginning with the newspapers, audio and video recording technology, radio, and television of the early- and mid-twentieth century, to the computer, the Internet, and various versions of digital audio and video storage, transmission, and playback formats of the late twentieth century and into the twenty-first century, all were no surprise to Marshall McLuhan's (1962) vision of the "global village." This has happened in two main ways. First, the cross-cultural consumption of music, in particular popular music, has increased in parallel with access to technological media. Second, technology, in particular the Internet and email, has facilitated the cross-cultural sharing of music and teaching methods and has greatly facilitated cross-cultural collaborative research among researchers from different geographic locations. The flow of musical and pedagogical information does not have to rely on physical travel anymore. Electronic transmission and digital storage have provided much convenience and reliability for musicians and educators to share information almost instantaneously, regardless of national boundary.

The United Nations and Their Subsidiary Organizations in Music

Formation of the United Nations in 1945 and their subsidiaries in music in the following years have brought to music educators a heightened need to be part of an international community. The United Nations Educational, Scientific and Cultural Organization (UNESCO), formed in 1945, was the parent organization of the International Music Council (IMC), founded in 1949, which aims at promoting musical diversity and building peace and understanding among peoples of all cultures and heritage. Under the auspices of IMC, the International Society for Music Education (ISME) was founded in 1953, started by a group of musicians from Europe and North America interested in the music education of youth and adults (McCarthy 2004). The mission of ISME was established, developed, and spread in the following decades. Included in its core values is to build and maintain a worldwide community of music educators. In 2010, it has members in 112 nations across all continents, realizing its mission toward a global community of music educators. Its biennial world conferences are the highlights of many music educators interested in international affairs in the field. Its publications also provide music educators an avenue to share their work in this worldwide network.

The value of indigenous way of understanding music purported in ethnomusicology, the increasingly systematic methods in comparative music education, the ever-accessible media and technology in digital formats and various high-speed transmission modes, and the political impetus for world peace and a worldwide community in music have all contributed to an elevation of international perspectives in music instruction and learning. The awareness of such perspectives seems to be continuing to increase as more researchers are incorporating data from international sources.

Important Scientific Research and Open Questions

Studies in international perspectives in music instruction and learning may be classified into those that (a) amount to philosophical statements designed to be global in concept, (b) relate to formal, systemic provisions for music education, which may be single national studies or comparative studies involving two or more nations, and (c) relate to nonsystemic cultural transmission, which could be mono-cultural or cross-cultural (Kemp and Lepherd 1992). Due to the developing nature of research in this field, some questions have remained open for decades. For example, how could one truly understand a practice without understanding the practices of others? How would one know if a strategy that is working well in one situation would work as well in another setting? While these questions are still open, similar questions had been implied in as early as the 1960s (Cykler 1961). As researchers are realizing the complexity of national and international issues in music instruction and learning, another broad question arises: To what extent are music-teaching methods related to various aspects of a society (such as political system, economy, religion, gender roles, etc.)? To put the matter in a global context and to consider music as a universal gift to people of all cultures and all ages, how could music instruction and learning be more equitable across nations, in terms of accessibility to music instruction?

Cross-References

► Cultural Learning
► Intercultural Learning
► Learning in Multicultural Societies
► Multicultural Issues in Music Instruction and Learning
► Music Instructional Methods
► Social Psychology of Music Instruction and Learning
► Sociocultural Research on Learning

References

Cykler, E. (1961). Comparative music education. *International Music Educator, 4*, 140–142.

Haydon, G. (1941). *Introduction to musicology: A survey of the fields, systematic & historical, of musical knowledge & research*. Chapel Hill, NC: The University of North Carolina Press.

Kemp, A. E., & Lepherd, L. (1992). Research methods in international and comparative music education. In R. Colwell (Ed.), *Handbook of research on music teaching and learning* (pp. 773–788). New York: Schirmer Books.

Kertz-Welzel, A. (2008). Music education in the twenty-first century: A cross-cultural comparison of German and American music education towards a new concept of international dialogue. *Music Education Research, 10*(4), 439–449.

McCarthy, M. (2004). *Toward a global community: The International Society for Music Education 1953–2003*. Western Australia: International Society for Music Education.

McLuhan, M. (1962). *The Gutenberg galaxy: The making of typographic man*. Toronto: University of Toronto Press.

Merriam, A. (1977). Definitions of "comparative musicology" and "ethnomusicology": An historical-theoretical perspective. *Ethnomusicology, 21*(2), 189–204.

Internet Literacy

► General Literacy in a Digital World

Internet-Based Learning Network

► Asynchronous Learning

Internship

► Learning in Practice and by Experience

Interpersonal Curiosity

Jordan A. Litman, Mark V. Pezzo
Psychology Department, University of South Florida, Saint Petersburg, FL, USA

Synonyms

Curiosity about people; Social curiosity

Definition

Interpersonal curiosity is the desire for new information about people, including details about others' life experiences, their public and private activities, and also their internalized thoughts, feelings, and motives. Interpersonal curiosity can motivate both overt and covert information-seeking behaviors, such as asking people questions directly or surreptitiously eavesdropping on them, respectively. Three dimensions of interpersonal curiosity have been identified: Curiosity about Emotions (CE), reflected in a desire to learn people's feelings; a willingness to engage in Spying and Prying (SP) in order to learn about people's interests and life experiences; and Snooping (Sn), which involves investigating people's personal surroundings or going through their belongings. Once activated, the degree to which interpersonal curiosity is experienced and expressed is theorized to vary due to individual differences in interpersonal curiosity as a dispositional trait (Litman and Pezzo 2007; Renner 2006; Singer and Antrobus 1963).

Interpersonal curiosity is positively correlated with epistemic curiosity, particularly deprivation-type, suggesting that most of the pleasure derived from learning about others is due to uncertainty reduction rather than the stimulation of interest (Litman and Pezzo 2007). The relationship between interpersonal curiosity and other forms of social interaction is complex; it is found positively associated with tendencies to share gossip, but is inconsistently related to extraversion (generally stronger for overt forms, weaker for covert forms) and concerns about social presentation (in general, weakly or negatively related). Overt expressions of interpersonal curiosity tend to be negatively associated with anxiety, while covert expressions tend to be positively related, suggesting that anxiety may inhibit aspects of interpersonal curiosity that require overt social interaction but facilitate gathering information about others covertly (Litman and Pezzo 2006, 2007; Renner 2006).

Theoretical Background

Early attempts to study interpersonal curiosity primarily focused on dispositional tendencies to passively wonder about people's day-to-day life experiences (Singer and Antrobus 1963). However, little consideration was initially given toward being curious about people's internalized life experiences, such as their thoughts or feelings, although these are significant sources of information about others (Fiske 1995). Early work on interpersonal curiosity (Singer and Antrobus 1963) also neglected to take into account the role of relevant information-seeking behaviors such as asking questions or spying, which may be influenced by social approval constraints or experiences of anxiety. Recent research by Renner (2006) and by Litman and Pezzo (2007) have endeavored to address limitations of past research on interpersonal curiosity by developing new measures of individuals differences in tendencies to engage in various kinds of overt and covert behaviors in order to learn about others.

Important Scientific Research and Open Questions

The new measures of interpersonal curiosity were only recently developed, so much more research needs to be conducted in order to determine whether individual differences in each interpersonal curiosity dimension predict relevant information-seeking behaviors, such as inquiring about people's feelings (CE) or their daily activities (Sn), or expending effort to pry into others' private affairs (SP). It will also be important to investigate how dispositional tendencies to experience and express interpersonal curiosity interact with social skills and the ability to understand the needs and feelings of others during social interactions.

Cross-References

► Adaptation and Learning
► Curiosity and Exploration
► Divergent Thinking and Learning
► Epistemic Curiosity
► Motivation and Learning
► Play, Exploration and Learning
► Social Interactions and Learning

References

Fiske, S. T. (1995). Social cognition. In A. Tesser (Ed.), *Advanced social psychology*. New York: McGraw Hill.

Litman, J. A., & Pezzo, M. V. (2006). Individual differences in attitudes towards gossip. *Personality and Individual Differences, 38*, 963–980.

Litman, J. A., & Pezzo, M. V. (2007). Dimensionality of interpersonal curiosity. *Personality and Individual Differences, 43*, 1448–1459.

Renner, B. (2006). Curiosity about people. *Journal of Personality Assessment, 87*, 305–316.

Singer, J. L., & Antrobus, J. S. (1963). A factor-analytic study of daydreaming and conceptually-related cognitive and personality variables. Perceptual and Motor Skills *17*(1), 187–209.

Interpretation-Based Learning

► Inferential Learning and Reasoning

Interproblem Learning

► Learning Set Formation and Conceptualization

Inter-psychological Processes

► Guided Learning

Interrelatedness

► Psychodynamics of Team Learning

Intersensory Facilitation

Hans Colonius[1], Adele Diederich[2]
[1]Department of Psychology, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany
[2]Jacobs University Bremen, Bremen, Germany

Synonyms

Crossmodal facilitation; Intersensory interaction; Multisensory integration

Definition

Intersensory facilitation occurs if the response to a stimulus, or a set of stimuli, from one sensory modality is in some way furthered by the concurrent stimulation of one or more other sensory modalities. The facilitation may manifest itself as: (1) a speed-up of reaction time, (2) a lowering of the sensory threshold for detection or discrimination of stimuli, or (3) an increase in the rate of recognition, identification, or classification of stimuli, or in particular stimulus qualities like loudness or brightness. Intersensory facilitation is part of a more general class of crossmodal phenomena including ► intersensory suppression and crossmodal illusions like ► ventriloquism.

Theoretical Background

Research on intersensory interaction and its underlying multisensory integration mechanisms has seen a tremendous increase over the last 20 years, spearheaded by neurophysiologists demonstrating the existence of ► multisensory neurons in several midbrain areas of various animals (Stein and Meredith 1993). However, experimental studies of intersensory facilitation can be traced back to psychologists in the 1910s (Todd 1912) and has been a persistent theme in experimental psychology and sensory psychophysics (Hershenson 1962; Marks 1978). The great majority of these studies have involved vision and audition, with an increasing consideration of their interaction with the haptic-somatosensory modality more recently. Intersensory interaction effects also play an increasingly important role in the development of virtual reality devices and the design multimodal man–machine interfaces.

Studies of synesthesia and crossmodal similarity have found the existence of certain correspondences between sensory dimensions in different modalities, for example, between loudness and brightness, or pitch and brightness, and these correspondences tend to show up in intersensory interaction experiments as well; for example, when a subject tries to identify a light as dim or bright, each light accompanied by a tone that may be low or high in pitch, performance is more accurate on those trials in which pitch is congruent with brightness (low pitch ≈ dim light, high pitch ≈ bright light) rather than incongruent, although the tones are irrelevant to the task. The mechanisms underlying such effects are still under debate: In some cases, especially in stimulus identification, the congruence relations may reflect learned associations between the stimuli. The main issue is if (1) crossmodal effects reflect early sensory interactions among the neural responses triggered by the different modalities or (2) they can be explained by relatively late decisional processes. In case (1), improved crossmodal detection performance, for example, could simply be due to probability summation, that is, the probability that at least one of two sensory activations exceeds a given threshold is higher than for either of the unimodal activations to exceed it. In case (2), the presence of a congruent auditory stimulus might bias the response to a visual stimulus by lowering the detection criterion for responding without affecting the perceptual representation of the visual stimuli. Of course, the two explanations do not exclude each other, and current research employs concepts from ► signal detection theory to explore the issue, using different combinations of modalities and varying levels of stimulus complexity in different experimental settings.

Turning to reaction time as dependent measure, effects of intersensory facilitation have been observed under two different experimental paradigms:

- In the *redundant target paradigm*, two (or more) stimuli are presented simultaneously, or with a short delay between the stimuli. The task of the participant is to respond, as quickly as possible, to the stimulus detected first.
- In the *focused attention paradigm*, two (or more) stimuli are presented simultaneously, or with a short delay between the stimuli. The task of the participant is to respond, as quickly as possible, to a predefined stimulus (the target) and to ignore the other stimuli (the nontargets).

The occurrence and amount of facilitation follow a number of rules:

1. Speed-up of reaction time to a crossmodal stimulus set is maximal when the stimuli of different modality are presented in close temporal-spatial proximity; for spatially disparate crossmodal stimulus pairs, no facilitation or even suppression may occur.
2. Speed-up of reaction time to a trimodal (visual-auditory-tactile) stimulus tends to be larger than to a bimodal stimulus set, even though, in the focused attention paradigm, the nontarget stimuli are irrelevant to the task.
3. Speed-up of reaction time to a crossmodal stimulus set, relative to the reaction time to a unimodal stimulus, tends to be smaller with increasing stimulus intensity levels ("inverse effectiveness" principle).
4. Intersensory facilitation occurs, in more or less similar fashion, in different response modes: finger/foot button press or release, saccadic eye movement, and head movement.

Current models of intersensory facilitation of reaction time can roughly be divided into two classes: *separate activation* models and *coactivation* models. Separate activation models, also known as *race models*, assume that (1) presenting a crossmodal stimulus produces parallel separate activation in different sensory channels that build to the level at which they can produce a response and (2) the response is triggered by the signal that reaches that level first. Assuming statistical variability in the channel processing times, separate activation models predict faster average reaction time to crossmodal stimuli than to unimodal stimuli because the average of the winner's processing time is smaller than the average processing time in each single channel ("statistical facilitation"). Writing RT_V, RT_A, and RT_{VA} for the reaction time random variables in the unimodal (e.g., visual and auditory) and bimodal conditions, respectively, Miller (1982) suggested the following distribution inequality which – given some technical assumptions – puts an upper bound on the amount of intersensory facilitation consistent with separate activation models:

$$Prob(\mathrm{RT}_{VA} \leq t) \leq Prob(\mathrm{RT}_V \leq t) + Prob(\mathrm{RT}_A \leq t),$$

for all time points t. This inequality has become a standard tool for testing if intersensory facilitation can be explained by a purely statistical effect (probability summation). Its frequent violation, for small values of t, points to the alternative *coactivation* class of models, which postulate that activation, raised in different sensory channels by presenting crossmodal stimuli, is combined to satisfy a single criterion for response initiation. Coactivation models predict faster average reaction time to crossmodal stimuli because the combined activation reaches that criterion faster. The most important instantiation of this approach is the *superposition* concept: Each stimulus triggers a sequence of "events" over time that is accumulated until a certain preset criterion is reached and a response initiated. For crossmodal stimuli, these "events" are combined additively. Many different realizations of this stochastic process modeling approach exist, like discrete-state counter models or diffusion models, and coactivation models tend to give good fits to experimental data (Diederich and Colonius 2004).

Important Scientific Research and Open Questions

The neural underpinnings of intersensory interaction are still under investigation utilizing a host of different techniques and approaches: Single- and multiple-cell recordings in various brain areas, neuroimaging techniques, transcranial magnetic stimulation, and computational neural modeling. There is converging evidence that the response activation patterns of multisensory neurons in various (mid)brain areas follow rules resembling those of intersensory facilitation of reaction time listed above, but the reduction of behavioral data to the response properties of large populations of neurons remains to be resolved. Moreover, neuroimaging studies have revealed that, for example, auditory stimulation not only elicits activation in the auditory cortex, but also in visual sensory cortices and vice versa; however, the anatomical foundations of these observations are still under discussion and, in particular, not much is known about the time course of multisensory integration processes. Nevertheless, there is growing support for the hypothesis that coherence of oscillatory responses at the level of primary sensory cortices may play a crucial role. At the computational modeling level, it has been recognized that integrating crossmodal information implies a decision about whether or not two (or more) sensory cues originate from the same event, that is, have a common cause. Several research groups have shown that crossmodal integration more or less closely follows rules based on optimal Bayesian inference procedures.

The hypothesis of a *temporal window of integration* has enjoyed increasing popularity as an important determinant of the dynamics of crossmodal integration. It holds that information from different sensory modalities must not be too far apart in time so that integration into a multisensory perceptual unit may occur. For example, in the area of audiovisual speech perception, if auditory speech lags behind matching visual speech, that is, lip movements, by more than 250 ms, the asynchrony will be perceived by the human observer. Similarly, when a sensory event simultaneously produces both sound and light, we usually do not notice any temporal disparity between the two sensory inputs (within a distance of up to 26 m), even though the sound arrives with a delay, a phenomenon sometimes referred to as *temporal ventriloquism*. Estimates of the width of the time window vary considerably according to the specific context. A quantitative model for a time window of integration mechanism in the area of reaction time studies has been developed and experimentally tested (see Diederich and Colonius 2004).

Cross-References

► Association Learning
► Audio–Video-Redundancy in Learning
► Audiovisual Learning
► Bayesian Learning
► Cross-Modal Learning (AI)
► Human Causal Learning
► Mental Chronometry
► Modality Effect
► Redundancy Effect
► Sensorimotor Adaptation

References

Diederich, A., & Colonius, H. (2004). Modeling the time course of multisensory interaction in manual and saccadic responses. In G. A. Calvert, C. Spence, & B. F. Stein (Eds.), *The handbook of multisensory processes* (pp. 395–408). Cambridge: The MIT Press.

Hershenson, M. (1962). Reaction time as a measure of intersensory facilitation. *Journal of Experimental Psychology, 63*, 289–293.

Marks, L. E. (1978). *The unity of the senses: Interrelations among the modalities*. New York: Academic.

Miller, J. (1982). Divided attention: Evidence for coactivation with redundant signals. *Cognitive Psychology, 14*, 247–279.

Stein, B. F., & Meredith, M. A. (1993). *The merging of the senses*. Cambridge: The MIT Press.

Todd, J. W. (1912). Reaction to multiple stimuli. *Archives of Psychology, 21*(25), 1–65.

Intersensory Interaction

► Intersensory Facilitation

Inter-sensory Suppression

This term is the antonym to "inter-sensory facilitation" and is used for a slowing down of reaction time, an increase of threshold, etc., by concurrent stimulation from an additional modality.

Intertrial Interval

The duration of time between consecutive CSs or learning trials.

Intrinsic Motivation

► Curiosity and Exploration
► Flow Experience and Learning

Intrinsic Reward System

► Multifaceted Model of Intrinsic Motivation

Introspection

► Self-Reflecting Methods of Learning Research

Introspective Learning and Reasoning

David B. Leake
School of Informatics and Computing, Indiana University, Bloomington, IN, USA

Synonyms

Metacognition; Metareasoning; Self-regulated learning

Definition

► Introspective reasoning is a form of metareasoning in which an agent reasons about the mental objects and actions involved in its own internal reasoning processes. Introspective reasoning may guide adjustments of domain-level reasoning processes, based on internal performance goals and self-knowledge about the agent's reasoning capabilities. Introspective learning is learning an agent performs, using introspective reasoning, to improve the future performance of its reasoning processes. The study of introspective reasoning and learning focuses on how intelligent systems – human or machine – can monitor and understand their own reasoning processes, and can exploit the resulting self-awareness to improve the performance of those processes.

Theoretical Background

Metareasoning has been studied in many disciplines, including psychology, education, computer science, and artificial intelligence. As Herbert Simon observed in the 1950s, human reasoning takes place under resource constraints. Reasoning under conditions of limited information, limited internal reasoning resources, and limited time applies to artificial intelligence (AI) systems as well. Much artificial intelligence research on metareasoning is motivated by the desire to enable AI systems to reason as effectively as possible under conditions of ► bounded rationality by selecting reasoning strategies appropriate to their constraints.

Interest in the nature of human self-awareness and self-regulation has a long history. More recently, artificial intelligence research has provided mechanistic explanations of introspection, applied in intelligent systems (see Cox 2005, for an overview of some of this work). For example, seminal work by Flavell in the 1970s began the study of metamemory, the phenomenon of conscious awareness by an individual of the contents and processes of his own memory (e.g., knowing that some types of facts are difficult to remember), leading to general studies of human metareasoning and cognitive monitoring (Flavell 1987). Research on expertise suggests that metacognitive abilities play an important role in problem-solving performance, and education research has studied ► self-regulated learning and instructional strategies aimed at improving metacognitive processes in students. Research on computational models of introspective reasoning and learning includes both cognitive science research aimed at modeling human reasoning, and artificial intelligence research aimed at understanding the space of architectures for introspective reasoning and their knowledge requirements, regardless of whether their approaches occur in human reasoning. Metareasoning can serve a wide range of tasks such as assessing the level of confidence in a system's beliefs (e.g., based on their derivations), to select which reasoning procedure to use for a given problem (e.g., by analytic methods, Russell and Wefald 1991), or to determine gaps in an understander's knowledge to be filled by learning (see Cox and Raja 2011, for a collection of examples).

Raja and Cox (2011, Chap. 1) propose that metacognition can be characterized in terms of a framework with three levels, the ground level, object level, and meta level (in principle, any meta-level process can itself be monitored and acted upon by another meta-level process; in practice, higher-level introspection has received little study). The ground level refers to the external environment in which the agent functions. The agent monitors the ground level through sensors and acts on it with effectors. The object and meta levels are both internal reasoning levels. Ground-level sensors provide percepts to the object level, which represents and reasons about objects, states, and events at the ground level. Based on its reasoning and its goals for the ground level, it acts on the ground level. Object-level processing and the object levels are themselves monitored by the meta level, which captures its own representations of object-level phenomena, and can act on the object level.

Introspective learning refers to meta-level analysis of the object or meta level and resultant modifications of their processes or representations, to improve their performance For example, introspective learning might revise aspects of object-level reasoning procedures or representations to address bugs, to decrease the time or space they require, to add new procedures, to reorganize knowledge, or to generate new ► knowledge goals and plans for ► goal-driven learning (Ram and Leake 1995).

To enable flexible self-debugging, introspective learning may use explicit declarative self-models of the agent's function and desired behavior. Introspective learning differs from domain learning in that introspective reasoning systems are normally assumed to have full access to their internal processes, unlike domain learning systems, which may have limited access to the ground level processes about which they learn. Likewise, introspective reasoning and learning are domain-independent, even though their effects may affect problem-solving in a particular domain (e.g., reorganizing domain-specific knowledge).

Introspective learning may be driven by success (for example, to favor a reasoning strategy which has proven surprisingly effective) or failure (to avoid repeating the failure in similar future situations). For failure-driven learning, a system may detect failures by comparing actual reasoning performance to expectations generated from an idealized self-model of high-level reasoning goals. Because the model characterizes desired performance, deviations from that desired performance suggest opportunities for learning, regardless of whether ground-level goals succeeded or failed: A system may succeed in its task despite flawed reasoning (e.g., if a planner fails to consider a possible threat, but that threat does not materialize), or may fail despite optimal reasoning, due to unforeseeable factors.

As a concrete example, model-based introspective reasoning has been applied for index refinement in ROBBIE, an agent that performs ► case-based reasoning – solving new problems by retrieving records of prior problem-solving for similar prior problems, and adapting their solutions to fit. A central premise for desired behavior of a case-based reasoning system is that the system's retrieval mechanism will retrieve the most relevant prior case or cases. When the system retrieves the wrong case (in this system, as revealed after the fact by comparing the final successful plan to plans already in memory), the system diagnoses the source of the problem. If the system determines that the indices used for retrieval omitted an important feature, introspective learning revises the system's indexing scheme to add the missing feature (Leake and Fox 2001). Note that this learning does not directly affect the system's domain knowledge – its set of cases – but instead improves the system's process for accessing the case knowledge the system has. Because re-indexing may enable use of existing knowledge in new contexts, it can support a form of creativity.

Important Scientific Research and Open Questions

In computational research on introspective reasoning and learning, many questions remain for determining when and how to learn, such as how to develop general methods for detecting internal failures and focusing resulting learning, and how to perform credit/blame assignment when analysis of the self-model suggests that multiple points may contribute to an internal reasoning failure. Existing research has often focused on applying a single learning methods to a single category of failure, leaving significant opportunities for investigation of multistrategy approaches to introspective learning.

In model-based introspective reasoners, the self-model provides a "gold standard" against which to compare system performance to detect problems. However, in practice, the self-model may not be perfect, and acquiring good models is costly. Consequently, another open area is how an introspective reasoner might debug an existing self-model, or to develop or refine its own model over time, as well as how to connect its self-model to regulation of its own reasoning behavior. Introspective reasoning systems able to explain their own reasoning to themselves and learn from those explanations – as a form of ► self-explanation, as studied by Chi, VanLehn, and collaborators – are another interesting area, as are introspective systems able to participate in collaborative processes with students and others.

Thus current research has provided many pieces of the puzzle of introspective reasoning and learning, but a continuing challenge is integrating these pieces into general models encompassing and integrating sufficient knowledge for systems to construct their own introspective policies. Such work might both provide hypotheses on the nature of human introspective learning and illuminate new ideas for how to enhance that learning.

Cross-References

- ► Artificial Intelligence and Machine Learning
- ► Computational Models of Human Learning
- ► Introspective Learning to Build Case-Based Reasoning
- ► Metacognition and Learning
- ► Self-regulated Learning

References

Cox, M. T. (2005). Metacognition in computation: A selected research review. *Artificial Intelligence, 169*(2), 104–141.

Cox, M. T., & Raja, A. (Eds.). (2011). *Metareasoning: Thinking about thinking*. Cambridge, MA: MIT Press.

Flavell, J. H. (1987). Speculation about the nature and development of metacognition. In F. Weinert & R. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 21–29). Hillsdale: Lawrence Erlbaum.

Leake, D., & Fox, S. (2001). Introspective reasoning for index refinement in case-based reasoning. *Journal of Experimental & Theoretical Artificial Intelligence, 13*(1), 63–88.

Ram, A., & Leake, D. (Eds.). (1995). Learning, Goals, and Learning Goals. *Goal-driven learning* (pp. 1–37). Cambridge: MIT Press.

Russell, S., & Wefald, E. (1991). Principles of metareasoning. *Artificial Intelligence, 49*(1–3), 361–395.

Introspective Learning to Build Case-Based Reasoning

Susan Craw
IDEAS Research Institute, Robert Gordon University, Aberdeen, UK

Synonyms

Experience-based reasoning; Introspective reasoning; Lessons-learned systems

Definition

Wikipedia defines introspection as "the self-observation of one's mental processes." Introspective learning occurs when an agent applies self-observation to its reasoning processes in order to improve its problem-solving performance. Case-based reasoning solves problems by retrieving stored experiences of previous problem-solving that are similar to the new problem, and reusing the solutions of these similar experiences. Applied to case-based reasoning, introspective learning observes and critiques the reasoning that has been applied. Therefore, it analyzes what experience is retrieved, why it is retrieved, and how the experience is reused, so that it may consider and evaluate alternative reasoning options that might achieve preferable problem-solving activity. The outcome of introspective learning for case-based reasoning is an adaptation of one or more of the core components of case-based reasoning: the case knowledge, retrieval mechanisms, or reuse methods.

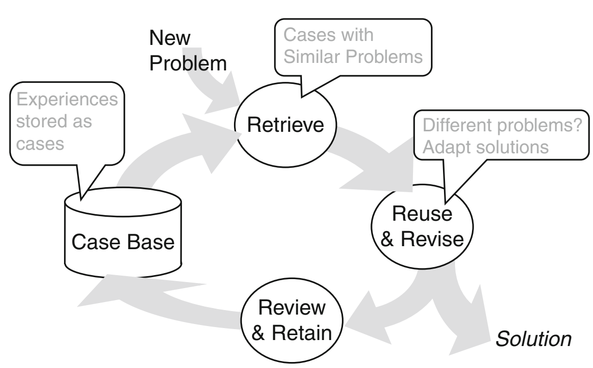
Theoretical Background

In psychology, human reasoning is associated with cognition and so introspection is cognition of one's own cognitive processes. Therefore, human introspection is a form of metacognition, being cognition about cognition. In artificial intelligence (AI), cognitive processes are achieved using beliefs and reasoning about these beliefs. In this way metacognition for humans is analogous with meta-reasoning, or reasoning about reasoning, in intelligent systems. Cox (2005) explores human metacognition in psychology, its analogues in computational theories of AI, and the integration of metacognition in computer-based reasoning systems such as model-based reasoning and case-based reasoning.

Case-based reasoning (CBR) is both a problem-solving methodology and a problem-solving technology. The CBR methodology applies in both humans and computer-based systems. Experiences of past problem-solving are stored in memory as cases, comprising problems and their solutions. When a new problem presents itself, the cases in memory are searched to identify a past case that has a similar problem to the new problem. This similar case is retrieved and its solution may be reused as a target solution for the new problem. Differences between the new and retrieved problems may require some revision of the retrieved solution before it is presented as a solution. Newly solved problems are available as new cases to be stored in memory for retrieval and reuse in the future.

CBR technology is a computer-based system that implements a case-based problem-solving methodology. The memory is a database of stored cases, the case base. Retrieval uses a similarity-based matching algorithm to identify the nearest neighbors of the new problem in the case base. A k nearest neighbor ($k-NN$) algorithm identifies the cases to be retrieved and reuses their solutions to propose an initial solution. An adaptation method revises the initial proposed solution to take account of differences between the new and retrieved problems. Finally the newly solved problem may be stored in the database as a new case. Figure 1 illustrates the R^4 Retrieve–Reuse–Revise–Retain cycle for CBR introduced by Aamodt and Plaza (1994).

CBR is a form of lazy learning because no generalized model of the learned concept is built. Instead, each time CBR is used, the cases are searched for the



Introspective Learning to Build Case-Based Reasoning. Fig. 1 Case-based reasoning cycle nearest neighbor. Therefore, the case-based memory itself is the primary source of knowledge and reasoning is achieved through the retrieval and reuse of cases. Although the cases are the main knowledge source, there are other knowledge containers that contribute to the reasoning. Michael Richter's invited talk at the first International Conference on Case-Based Reasoning proposed three fundamental knowledge containers in addition to the case base itself: representation language (vocabulary); similarity measure; and adaptation knowledge. The representation language and case base together capture and index the case knowledge as CBR memory. The similarity measure is defined by the similarity assessment for features together with the feature selection and weighting. The adaptation knowledge captures revisions that depend on problem differences, refinements to an initial solution rather than problem-solving from scratch.

Traditionally, introspective learning has been triggered as a failure-driven learning where the faulty reasoning has been explored, explanations proposed for it, and the faulty reasoning has been repaired (Cox 2005). For CBR, introspective learning has explored the CBR reasoning behind the faulty problem-solving based on the cases in the case base, the representation/indexing of these cases, the similarity measure for retrieval and the adaptation knowledge for revision.

However, human introspective learning can also include introspection of memory and re-indexing from this self-reflection. The central role of the cases in CBR has also meant that introspection of the case memory has also provided an opportunity to learn knowledge for the case-based memory and other knowledge containers. This more recent form of introspective learning for CBR has assumed that the case base is a representative sample illustrating the problem domain, and uses the cases as test data to learn case knowledge, indexing, retrieval, and adaptation knowledge (Craw et al. 2006; Smyth and McKenna 2001).

Important Scientific Research and Open Questions

Case learning occurs naturally as the Retain phase of the R^4 CBR cycle. In this way, the case base is continually growing with cases capturing the solutions of new problems. Here learning achieves knowledge acquisition for the case base knowledge container.

Introspective learning is learning from failure by attempting blame assignment and an explanation for the faulty reasoning. Early forms of introspective learning for CBR accessed a model of the failure types to reason about the failures. Cox's (2005) Meta-Aqua is a meta-reasoner for the Aqua story understanding system. When a story understanding failure occurs, Meta-Aqua uses meta-explanation patterns (MXPs) to identify how Aqua's story understanding failure occurred using trace MXPs, and why the failure occurred using introspective MXPs. The failure model had repairs that could be applied to overcome the failure and to annotate the retrieved case with the repair for this failure.

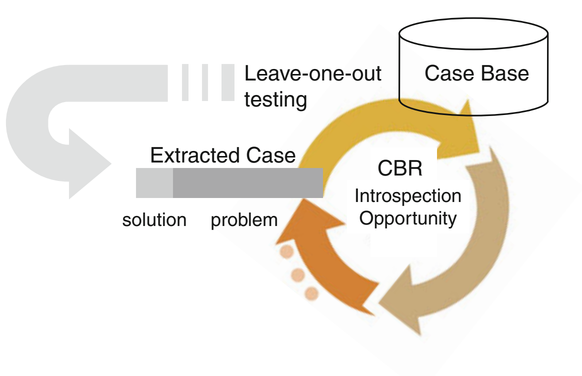
Fox and Leake's (1995) ROBBIE system is a case-based planner for navigation by a robot. ROBBIE incorporates introspective learning to acquire knowledge for the case representation knowledge container that allows re-indexing of the existing cases. ROBBIE's case-based planner uses the standard CBR cycle to retrieve a navigation case with similar starting and/or ending positions and executes the retrieved plan. The execution can alter the proposed plan (e.g., by removing redundant steps) and the revised plan triggers introspective learning. Are there cases in the case base whose plans are similar to the revised plan? Introspection now reasons about the differences between this newly identified case and the previously retrieved case with respect to the navigation problem to be solved. In this way, ROBBIE discovers new features of the cases that are then captured in the case representation and used to re-index the cases. Thus knowledge acquisition has been achieved, not through the acquisition of new cases, but through the re-indexing of existing cases so that the more appropriate case will be retrieved in the future for similar cases.

Introspective learning for retrieval at this time applied a qualitative refinement of the weighting; e.g., lower the weighting. In contrast, Zhang and Yang's (2001) introspective feature weight learning is quantitative; i.e., the adjustment of weights provides the size of the change as well as the direction. It fits the traditional model of introspective learning since it refines the weights during interactions with multiple users who provide feedback on the retrieved solutions. Introspective learning occurs when negative feedback indicates a reasoning failure. A two-layer network links feature-value pairs to cases using weighted arcs;

a three-layer network adds a corresponding layer between cases and solutions. When a reasoning failure occurs, a weight update is undertaken to propagate the change that will result in the desired outcome. An approach similar to gradient-descent weight learning for a back-propagation neural network is used. In this system, introspective learning has been used to refine the similarity knowledge container for retrieval.

This section has focused up to now on failure-driven introspective learning during normal problem-solving of a CBR system. However, opportunities for introspective learning may occur by creating problem-solving opportunities and feedback on the proposed solutions from cases extracted from the case base. Self-modeling of the case base is one example of such introspection. Smyth et al.'s competence model uses local knowledge of the neighborhood of cases in the case base to model the problem-solving ability, or competence, of each case in the case base. From this stems the notion of footprints in the case base and their use to guide, and thus reason about, retrieval. Their competence model is the result of introspective learning and is used to inform various case base maintenance algorithms for case discovery and case base editing (Smyth and McKenna 2001).

Introspective learning through cases is also used in knowledge acquisition for knowledge containers beyond the case base. Test instances are created by extracting cases one at a time from the case base and using them as unseen problems for CBR but with known solutions (see Fig. 2). These test instances



Introspective Learning to Build Case-Based Reasoning. Fig. 2 Introspection from leave-one-out cases

are used within a wrapper approach to tune the retrieval method by selecting and weighting the retrieval features, or learning other parameters that affect retrieval. Thus introspective learning results in refined knowledge in the similarity/retrieval knowledge container.

A similar approach has been used to generate adaptation instances from which adaptation knowledge is learned. Here the introspective learning generates examples of adaptations that should be applied to revise the retrieved case into the known solution for the extracted case. Craw et al. (2006) have developed one such introspective learning of adaptation knowledge where the adaptation instances are viewed with different preferences and the resulting adaptation ensemble is able to trade off competing adaptations to reach a consensus adaptation.

Introspective learning for the remaining knowledge container, case representation, is commonly used in textual CBR (TCBR) for feature selection, extraction, and organization. A self-analysis of the terms in a collection of documents allows TCBR to create an indexing vocabulary and to generate structured representations. Latent Semantic Analysis (LSA) is one approach to identify semantic concepts that may be used as extracted textual features. Formal Concept Analysis (FCA) may be used to create a lattice of the features/concepts in the documents and, from this, build a hierarchy or ontology of related concepts from the documents.

Introspective learning from the case base has been used to reason about CBR reasoning and to amend the knowledge in the four knowledge containers. But does the case base capture richer experiences of problem-solving that together offer a more sophisticated meta-reasoning? By discovering different ways to apply CBR that uses parts of the experiences in cases in different ways, there is a more opportunistic, evidence-based reasoning that may open the door to strategy learning from introspective learning.

Cross-References

► Case-Based Learning
► Case-Based Learning on the Web
► Example-Based Learning
► Introspective Learning and Reasoning

References

Aamodt, A., & Plaza, E. (1994). Case-based reasoning: Foundational issues, methodological variations, and system approaches. *Artificial Intelligence Communications, 7*(1), 39–59. IOS Press. http://www.idi.ntnu.no/~agnar/publications/aicom–94.pdf. Accessed 18 Nov 2010.

Cox, M. T. (2005). Metacognition in computation: A selected research review. *Artificial Intelligence, 169*(2), 104–141. doi:10.1016/j.artint.2005.10.009.

Craw, S., Wiratunga, N., & Rowe, R. C. (2006). Learning adaptation knowledge to improve case-based reasoning. *Artificial Intelligence, 170*(16–17), 1175–1192. doi:10.1016/j.artint.2006.09.001.

Fox, S., & Leake, D. B. (1995). Using introspective reasoning to refine indexing, *Proceedings of the 14th International Joint Conference on Artificial Intelligence* (pp. 391–397). http://ijcai.org/Past Proceedings/IJCAI-95-VOL 1/pdf/052.pdf. Accessed 18 Nov 2010.

Smyth, B., & McKenna, E. (2001). Competence models and the maintenance problem. *Computational Intelligence, 17*(2), 235–249. doi:10.1111/0824-7935.00142.

Zhang, Z., & Yang, Q. (2001). Feature weight maintenance in case bases using introspective learning. *Intelligent Information Systems, 16*, 95–116. doi:10.1023/A:1011208900462.

Introspective Reasoning

► Introspective Learning to Build Case-Based Reasoning

Intuition

► Creativity, Problem Solving, and Feeling

Intuition Pumps and Augmentation of Learning

Jon Louis Dorbolo
Oregon State University, Corvallis, OR, USA

Synonyms

Allegory; Metaphor; Puzzle; Teaching story; Thought-experiment

Definition

Intuition pump denotes a family of techniques used to transform thought through reconceptualization. Dennett (1984) coined the term “intuition pump” in criticism of philosophers who persuade without recourse to logical argument. Dennet associates intuition pumps with *thought-experiments*, though the examples he gives include allegories, analogies, stories, metaphors, paradoxes, and puzzles. An analysis of these techniques shows that they include a broad range of cognitive and linguistic activities that operate in a variety of ways and leaves open the question whether they may be clustered under a single rhetorical category. Dennet’s (1984) point is that some techniques affect persuasion by means other than rigorous deliberation and tend to supplant logical argument. In voicing this concern he invokes long-standing questions in philosophy, psychology, science, and education about the relations between *intuition* and *deliberation*. The outcomes of those questions will determine whether and how intuitions, and intuition pumps, can be assets or obstacles to learning.

Intuition is typically defined in terms of *not* being the product of *conscious deliberation* (see Westcott 1968). The preponderance of negative definitions in the literature reflects the fact that we do not know how intuition works even though many of us experience intuition and its outcomes. Perhaps we do not know how conscious deliberation works either, but at least we can observe and track its procedure, for example, through internal reflection. Because of the nonconscious character of intuition, over the millennia it has been attributed to sources from the mystical to the irrational.

Several positive characteristics of intuition are distributed throughout the philosophical and psychological literature. Intuition is regarded as a mode of thought that occurs quickly, is based in experiential memory (Laughlin 1997), and affects other cognitive processes such as judgments, decisions, and actions (Betsch 2008). In order to provide a positive definition without presuming an explanation, the following is a synthesis of several authors’ characterizations: *Intuition* is a nonconscious mode of thought drawing from experiential memory to produce a felt conviction that may affect other thoughts, judgments, decisions, and actions. *Educational intuition pumps*, then, are techniques used to transform thoughts, convictions, judgments, decisions, and actions using intuitions elicited via reconceptualization in order to achieve a learning objective.

Theoretical Background

In Plato's dialogues, Socrates insists that the participants should begin deliberation by setting forth their genuine beliefs, usually as definitions. By systematically bringing beliefs into self-contradiction, Socrates often succeeded in creating a state of puzzlement (*aporia*) which is expressed as a need for cognitive resolution. In numerous cases, Socrates elicits his interlocutor's beliefs through intuition pumps, including myths, analogies, puzzles, paradoxes, and thought-experiments. Plato's *Meno* presents a prototypical example of Socratic method that results in transformed thinking subsequent to the use of both intuition pumps and logical analysis. Socrates' demonstration of innate knowledge by means of drawing out an uneducated child's intuitions about geometry shows that intuition pumps may take forms other than words and images. The many instances of intuition pumps in Plato's dialogues provide a meaningful juxtaposition of intuition and logical argument. Socrates uses both, and it is clear that he often regards the eliciting of intuition as a crucial precursor to cognitive change.

Descartes produces powerful intuition pumps and also codifies the central criterion in the traditional authority of reason over intuition. The key feature of true ideas and sound deliberation for Descartes is *transparency*. Thoughts display their veracity by being clear and distinct. Logical arguments display their soundness by being open to recapitulation and checking – the way that a calculation can be gone over and tested. The opaque character of intuition sets it in strong contrast to deliberation on the Cartesian view of how knowledge is possible.

Freud and Jung impact our understanding of intuition by making the ideas of the *nonconscious* usable in both science and philosophy. The nonconscious is nontransparent since its contents are not directly available to *awareness* and *introspection*. Yet nonconscious processes and beliefs interact with conscious thoughts and processes, and, as a consequence, are active in the formation of conscious states of mind, including beliefs, emotions, and perceptions.

With Piaget (1973) the issues of consciousness, cognition, intuition, and education come together in a systematic account of how the mind, and even culture, develops. Piaget distinguishes between the contents of cognition, which are the results of operations which enter our awareness, and the structures of cognition, which are underlying operations of which we remain unaware. On this model our conscious understanding is dependent upon nonconscious mechanisms. *Cognitive development* occurs as we become aware of previously nonconscious structures.

Of key significance in Piaget's theories is the notion that *awareness* creates change in the underlying nonconscious structures. Without some reciprocal agency of conscious cognitions upon nonconscious cognitions, Piaget's account of the human system would be a mere description of a deterministic mechanism. Instead, Piaget describes awareness as a response to *disadaptation*, where the conscious content comes into conflict with nonconscious structures. These conflicts produce awareness of the structures (at least in part) which creates *accommodation* in the underlying nonconscious *schemas*, leading to systemic cognitive change.

This account of cognitive change supports a model of designed uses of intuition for education. The positive account of *educational intuition pumps* given above accords with Piaget's (1973) model of nonconscious structures and the results of their coming into awareness. Piaget's theoretical background and empirical research into cognitive change sets the stage for contemporary pedagogies to make designed uses of educational intuition pumps.

Simon's (1957) introduction of *bounded rationality* altered the course of investigations into deliberation and *decision making* in economics, psychology, organization theory, political science, statistics, computer science, and education. Simon's *information processing* analyses of deliberation and *rationality* encourage new ways to think about the roles and uses of nonconscious operations such as intuition.

Betsch (2008) advances the information processing model as a basis for distinction between deliberate thought and intuition. Betsch (2008) characterizes higher-order deliberations as serial operations which are bounded by the limits of attention and working memory. By contrast, nonconscious cognitions, including intuition, are parallel processing operations performing quickly across large sets of long-term memory.

Hogarth (2001) brings the broad background of theory to bear in developing practical approaches to improving intuition. Hogarth (2001) argues that intuition can be learned and improved and proposes a seven-part strategy for doing so. This program is intended to make us better intuitive thinkers, bringing nonconscious operations more in accord with deliberative thought.

Many disciplines contribute to the background issues of intuition and uses of intuition pumps. The problems concerning cognitive change are ancient and persistent. The twentieth century brought increasingly sophisticated analyses of the mechanisms of intuition and cognitive change. In the twenty-first century there is a growing recognition of the importance of intuition in cognitive processes and the development of methods for improving intuition through education.

Important Scientific Research and Open Questions

What Are the Varieties of Educational Intuition Pumps?

Intuition pump was coined by Dennett (1984) for rhetorical rather than pedagogical purposes. His usage includes a wide range of imaginative and linguistic techniques, including thought-experiments, allegories, analogies, stories, metaphors, paradoxes, and puzzles. Authors following Dennett's usage assume a similar grouping, sometimes treating *intuition pump* as interchangeable with *thought-experiment*. It is not clear, however, that the techniques collected under the rubric *intuition pump* have relevant similarities in regard to form, function, process, cognitive effect, or educative value. Nor it is clear that all of the techniques operate specifically with intuitions. Scientific thought-experiments, for instance, are often designed as exercises in deliberation with the goal of making reasons explicit rather than eliciting nonconscious outcomes. Philosophical thought-experiments are designed to support, attack, or test theories by providing supporting cases or counter-examples. Neither form of thought-experiment is dependent upon intuitions.

Thought-experiments in general are distinct from some traditional techniques that fit the definition of *educational intuition pump*, such as Zen koans. Koans and other ancient methods function by posing a question that does *not* give way to an obvious example or simple solution. Koans operate differently than thought-experiments and for different purposes, yet both may draw on intuitions and function as educational intuition pumps. Koans and related techniques are significant examples because they are employed as didactic techniques aimed at provoking deeper understanding. Allegories, myths, metaphors, parables, puzzles, and paradoxes bring many variables to the intuition pump concept. Indeed, the phrase *intuition pump* is itself a metaphor. These varieties require careful analysis if they are to provide useful examples of educational technique.

Are Intuition Pumps Valuable in Education?

Whether, when, to what extent, and how intuition pumps are useful to education are issues open to further investigation. In some situations, intuition pumps may lead learners away from reasoned argument and deeper understanding. There is currently no objective methodology to evaluate intuitions. Science education, on the other hand, includes thought-experiments as a key tool in the teaching/learning repertoire. Many mathematicians regard intuition as basic to mathematical epistemology. There is ample practical evidence that intuition pumps have utility in many areas of education.

Educational practices worldwide and through the millennia provide models for uses of educational intuition pumps. Koans developed as formal techniques in Japan and China from the thirteenth century on. Platonic methods of myth and allegory influence the writing and lecturing of many disciplines over 2,500 years. Christian and Gnostic gospels use *oppositional pairs* as teaching techniques for inducing cognitive change. Many of the abovementioned teaching techniques continue to be demonstrated as effective in fostering conceptual cognitive change and promoting deep understanding. Whatever one maintains about teaching agendas and the priority of rationality, it remains true that human thought is affected by ancient linguistic and symbolic techniques now called *intuition pumps*. Their continued use and effectiveness suggest the need for further research into these phenomena. Remarkable instances of cognitive change do occur and we have yet to develop a strong explanation for them.

Sometimes teaching stalls against the conceptual limits of learners. When this happens we are apt to say that the information is *counter-intuitive* for those individuals. In teaching and learning it is often the case that merely presenting the truth, even when supported by evidence and reasoning, is not sufficient to overcome counter-intuitive responses. In such cases it may be that the intuition pump is an effective technique to bringing the learner to a state of receptivity. Intuition pumps may be useful when the learner has intuitions about their own capabilities that set limits on what they are willing to do or able to conceptualize.

Are Intuition Pump Outcomes Measurable?

It may be useful to explore intuition pump techniques by applying other models for altering nonconscious processes. One such model is *biofeedback* in which an individual learns increased control over an *autonomic* system via representations of the outputs of that system (e.g., heart rate, temperature, skin conductance, blood pressure, and brain waves). An implication of clinical biofeedback technique is that nonconscious processes may be deliberately influenced when results of those processes are perceptible by individuals in real time. Expressed intuitions are results of nonconscious processes. If techniques for measuring and representing intuitions were developed, the underlying processes producing intuitions may be open to conscious influence. Since intuition pumps are effective at eliciting intuitions, they are plausible candidates for developing such feedback techniques.

Cross-References

▶ Analogy/Analogies: Structure and Process
▶ Conceptual Change
▶ Deductive Reasoning and Learning
▶ Human Information Processing
▶ Piaget's Learning Theory
▶ Plato (429–347 BC)
▶ Schema(s)
▶ Schemas and Decision Making
▶ Simon, Herbert Alexander (1916–2001)
▶ Socratic Questioning

References

Bastick, T. (1982). *Intuition, how we think and act.* New York: Wiley.

Betsch, T. (2008). The nature of intuition and its neglect in research on judgment and decision making. In H. Plessner, C. Betsch, & T. Betsch (Eds.), *Intuition in judgment and decision making* (pp. 3–22). New York: Lawrence Erlbaum.

Dennett, D. (1984). *Elbow room: The varieties of free will worth wanting.* Cambridge: The MIT Press.

Hogarth, R. M. (2001). *Educating intuition.* Chicago: The University of Chicago Press.

Laughlin, C. (1997). The nature of intuition: A neuropsychological approach. In R. Davis-Floyd & S. Arvidson (Eds.), *Intuition: The inside story: Interdisciplinary perspectives* (pp. 19–37). New York: Routledge.

Piaget, J. (1973). *The child and reality.* New York: Grossman.

Simon, H. (1957). *Models of man.* New York: Wiley.

Westcott, M. R. (1968). *Toward a contemporary psychology of intuition: A historical, theoretical, and empirical inquiry.* New York: Holt, Rinehart & Winston.

Inventiveness

▶ Creativity and Its Nature

Involuntary Information Processing

▶ Automatic Information Processing

Involvement

▶ Measurement of Student Engagement in Learning

Involving

▶ Spatial Cognition in Action (SCA)

IQ

▶ Learning and Fluid Intelligence Across the Life Span

Irrational Belief Persistence

▶ Divergent Probabilistic Judgments Under Bayesian Learning with Nonadditive Beliefs

Iterated Learning

► Repeated Learning and Cultural Evolution

Iterative Control

► Iterative Learning Control

Iterative Learning Control

YangQuan Chen[1], Kevin L. Moore[2], Hyo-Sung Ahn[3]
[1]Department of Electrical and Computer Engineering, Center for Self-Organizing and Intelligent Systems (CSOIS) Utah State University, Logan, UT, USA
[2]Colorado School of Mines, Golden, Colorado, USA
[3]Gwangju Institute of Science and Technology, Buk-gu, Gwangju, Korea

Synonyms

Iterative control; Periodic learning control; Repetitive learning control

Definition

Iterative Learning Control (ILC) is a relatively recent, but well-established, area of study in control theory. Various definitions of ILC have been given in the literature. Some of them are quoted here (Ahn et al. 2007 and the references therein):

- The learning control concept stands for the repeatability of operating a given objective system and the possibility of improving the control input on the basis of previous actual operation data (Arimoto et al. 1984).
- It is a recursive online control method that relies on less calculation and requires less *a priori* knowledge about the system dynamics. The idea is to apply a simple algorithm repetitively to an unknown plant, until perfect tracking is achieved (Bien and Huh 1989).
- Iterative learning control is an approach to improving the transient response performance of the system that operates repetitively over a fixed time interval (Moore 1993).
- Iterative learning control considers systems that repetitively perform the same task with a view to sequentially improving accuracy (Amann et al. 1996).
- ILC is to utilize the system repetitions as experience to improve the system control performance even under incomplete knowledge of the system to be controlled (Chen and Wen 1999)
- The controller that learns to produce zero tracking error during repetitions of a command, or learns to eliminate the effects of a repeating disturbance on a control system output (Phan et al. 2000).
- The main idea behind ILC is to iteratively find an input sequence such that the output of the system is as close as possible to a desired output. Although ILC is directly associated with control, it is important to note that the end result is that the system has been inverted (Markusson 2002).
- We learned that ILC is about enhancing a system's performance by means of repetition, but we did not learn how it is done. This brings us to the core activity in ILC research, which is the construction and subsequent analysis of algorithms (Verwoerd 2004).

Theoretical Background

The world around us is evolving dynamically. Most natural and man-made systems are dynamical systems. Automatic control of a dynamic system aims to automatically adjust the system behavior to the desired behavior based on certain properly measured or sensed signal(s) to be fed back to the decision and control unit, generally called "feedback controller." Looking around, control systems are all around us: from hard disk drives to rice cooker, from toilet flush to car cruise control, from change of Federal Reserve rates to artificial pacemaker, etc.

Many man-made systems or machines perform the same task again and again (e.g., robots, batch reactors, and hard disk drive servos). "Iterative Learning Control (ILC)" is a control technique that specifically makes use of the repetitiveness to achieve better control performance with less modeling effort. ILC addresses the natural question "We human beings gain skills from repetitive practice, so do machines?" ILC has been proven to be an effective control tool for improving the transient response and tracking performance of uncertain dynamic systems that are operated repetitively such as a robotic manipulator in a manufacturing environment or a chemical reactor in a batch processing application. The ILC notion can also be extended to include periodically disturbed or periodically driven dynamic systems, where the periodicity could be time-, state-, or trajectory-dependent. More generally, the key idea of ILC can be viewed as a multi-pass repetitive process. Historically, the first novel idea related to a multi-pass control strategy can be traced back to a paper published in 1974 by Edwards and Owens, though the stability analysis was restricted to classical control concepts and did not explicitly cover the ILC approach. It is widely accepted that the first ILC formulations were given by Uchiyama which was written in Japanese and published in 1978, and by Arimoto et al. (1984) in English. Interestingly, the essential idea of iterative learning was captured even before 1970, not in the archival literature, but in US patent 3,555,252 "learning control of actuators in control systems."

All definitions about ILC have their own emphases. However, a common emphasis of these definitions is the idea of utilizing the "repetition." Following the above quoted definitions of ILC, we can say that ILC is an approach to improve the transient response performance of an unknown/uncertain hardware system that operates repetitively over a fixed time interval by using the previous actual operation data to compensate for uncertainty. The key question of ILC is how to eliminate the uncertainty by using past performance information on the current trial. If the system uncertainty and external disturbances are predetermined on the uniformly distributed repetitive time axis, then finding an "inverse" of these predetermined effects can be thought of as the main objective of ILC.

So, roughly speaking, the purpose of introducing ILC is to utilize the system repetitions as experience to improve the system control performance even under incomplete knowledge of the system to be controlled. Based on Arimoto's formulation, the mathematical description of ILC is as follows:

- *Dynamic system and control task*

  A general nonlinear dynamic system is considered. The system is controlled to track a given desired output $y_d(t)$ over a fixed time interval. The system is operated repeatedly and the state equation at the k-th repetition is described as follows:

$$\begin{cases} \dot{x}_k(t) = f(x_k(t),\ u_k(t)) \\ y_k(t) = g(x_k(t),\ u_k(t)) \end{cases} \tag{1}$$

  where $t \in 6$ [0,T]; $x_k(t)$,$y_k(t)$, and $u_k(t)$ are state, output, and control variables, respectively. Only the output $y_k(t)$ is assumed to be measureable and the tracking error at the k-th iteration is denoted by $e_k(t) \overset{\Delta}{=} y_d(t) - y_k(t)$.
- *Postulates*
  - **P1**. Every trial (pass, cycle, batch, iteration, repetition) ends in a fixed time of duration $T > 0$.
  - **P2**. A desired output $y_d(t)$ is given a priori over $[0,\ T]$.
  - **P3**. Repetition of the initial setting is satisfied, that is, the initial state $x_k(0)$ of the objective system can be set the same at the beginning of each iteration: $x_k(0) = x^0$, for $k = 1, 2, \cdots$.
  - **P4**. Invariance of the system dynamics is ensured throughout these repeated iterations.
  - **P5**. Every output $y_k(t)$ can be measured and therefore the tracking error signal, $e_k(t) = y_d(t) - y_k(t)$, can be utilized in the construction of the next input $u_{k+1}(t)$.
  - **P6**. The system dynamics are invertible, that is, for a given desired output $y_d(t)$ with a piecewise continuous derivative, there exists a unique input $u_d(t)$ that drives the system to produce the output $y_d(t)$.
- *Controller design task*

  The controller design task is to find a recursive control law

$$u_{k+1}(t) = F\left(u_k(t),\ e_k(t)\right) \tag{2}$$

  such that $e_k(t)$ vanishes as k tends to infinity.

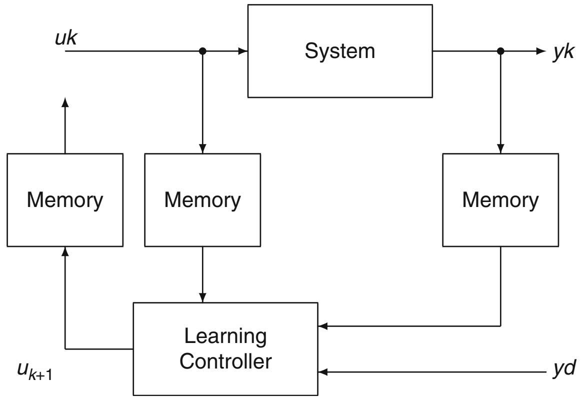
The simpler the recursive form $F(\cdot,\cdot)$, the better it is for practical implementation of the iterative learning control law, as long as the convergence is assured and the convergence speed is satisfactory. The above set of postulates reflects the program learning and generation for the acquisition of various kinds of fast but skilled movements. Physiology suggests that the ideal or desired pattern of motion must be acquired through a succession of trainings. Take sports for example; once an idealized form of motion is pointed out by the coach, one must repeat the physical exercises to make his or her motion approach or converge to the ideal form. Through a sufficient number of trials or repetitions, a program is formed in the Central Nerve System (CNS) which can generate a succession of input command signals that excites a certain system of muscles and tendons related to that ideal motion pattern and realizes the desired motion form.

It should be noted that various research efforts can be found in the literature targeting on relaxing the above postulates (**P**1–**P**5) (Ahn et al. 2007; Bristow et al. 2006). The basic idea of ILC is illustrated in Fig. 1 (Ahn et al. 2007). Standard assumptions are that the plant has stable dynamics or satisfies some kind of Lipschitz condition, that the system returns to the same initial conditions at the start of each trial and then the trial lasts for a fixed time T, and that each trial has the same length.

A typical ILC algorithm for the architecture shown in Fig. 1 has the form

$$u_{k+1}(t) = u_k(t) + \gamma \frac{d}{dt} e_k(t)$$

where $u_k(t)$ is the system input and $e_k(t) = y_d(t) - y_k(t)$, with $y_k(t)$ the system output and $y_d(t)$ the desired response. For a large class of systems this algorithm can be shown to converge in the sense that as $k \to \infty$ we have $y_k(t) \to y_d(t)$ for all $t \in [0, T]$. Notice that this algorithm appears to be noncausal. This is a key feature of ILC. Though the algorithm actually acts only on past data, the fact that the initial conditions are reset at the beginning of each trial allows us to do "noncausal" processing on the errors from the previous trial.



Iterative Learning Control. Fig. 1 Iterative learning control architecture

To illustrate the effectiveness of the ILC paradigm, consider the plant

$$x_{k+1} = \begin{bmatrix} -0.8 & -0.22 \\ 1 & 0 \end{bmatrix} x_k + \begin{bmatrix} 0.5 \\ 1 \end{bmatrix} u_k$$
$$y_k = [1,\ 0.5]\ x_k$$

Our goal is to track the reference trajectory: $Y_d(j) = \sin(8.0j/100)$. We assume zero initial conditions. Figure 2 shows the result of using the standard discrete-time "Arimoto" algorithm:

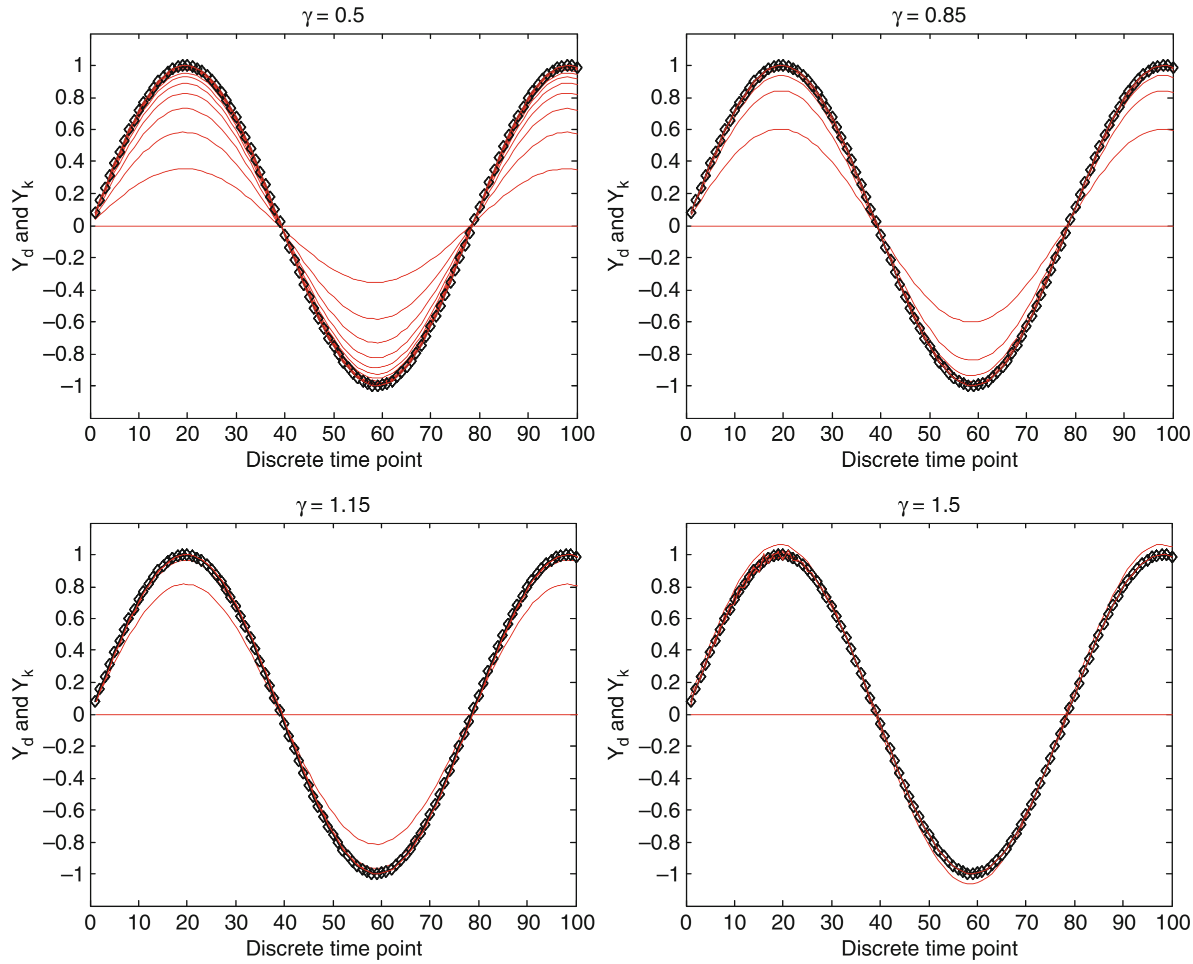
$$u_{k+1}(t) = u_k(t) + \gamma e_k(t+1)$$

with four different gains: $\gamma = 0.5$, $\gamma = 0.85$, $\gamma = 1.15$, $\gamma = 1.5$. For each gain, the ILC algorithm converges, but the convergence rate depends on γ. Without knowing an accurate model of the plant, we achieve "perfect" tracking by iteratively updating the input from trial to trial.

Important Scientific Research and Open Questions

It is believed that ILC is in general a matured method and is being turned into a technology for routine control engineering practice. More emphasis should be put on pursuing new ILC applications and the theoretical issues from the emerging new applications. The following is an incomplete list of potential further research opportunities (Moore et al. 2006):

- Transient and monotonic convergence issues were not well handled but are now gaining attention.
- Applications to PDE (partial differential equation) systems are not well understood.
- ILC for fractional order dynamic systems (polymer/piezo/silicone gel etc.).
- ILC for large-scale uncertain spatiotemporal interconnected systems.
- ILC in network control systems (NCS) setting (telepresence/tele-training).
- Intermittent ILC (intermittent sensing, actuation, learning updating).
- Asynchronous ILC. ILC with nonuniform sampling.



Iterative Learning Control. Fig. 2 An iterative learning control example

- Joint time-frequency domain ILC (techniques: wavelet, TFRs (time-frequency representations), even fractional order Fourier transform).
- Cooperative ILC with overpopulated (or densely distributed) sensors and actuators, possibly networked, each with dynamic neighbors under uncertain communication topologies.
- Iterative learning consensus building for collective iterative learning control.
- Memory and communication are getting cheaper and cheaper: Can we envision "ubiquitous collaborative iterative learning"?

Cross-References

► Adaptive Learning Systems
► Functional Learning
► Learning Algorithms

References

Ahn, H.-S., Moore, K. L., & Chen, Y. Q. (2007). *Iterative learning control: robustness and monotonic convergence in the iteration domain*. London: Springer-Verlag, Communications and Control Engineering Series.

Amann, N., Owens, H., & Rogers, E. (1996). Iterative learning control for discrete-time systems with exponential rate of convergence. *IEE Proceedings-Control Theory and Applications, 143*(2), 217–224.

Arimoto, S., Kawamura, S., & Miyazaki, F. (1984). Bettering operation of robots by learning. *Journal of Robotic Systems, 1*(2), 123–140.

Bien, Z., & Huh, K. M. (1989). Higher-order iterative control algorithm. *IEE Proceedings Part D, Control Theory and Applications*, 105–112.

Bristow, D. A., Tharayil, M., & Alleyne, A. G. (2006). A survey of iterative learning control: a learning-based method for high-performance tracking control. *IEEE Control Systems Magazine, 26*(3), 96–114.

Chen, Y. Q., & Wen, C. (1999). *Iterative learning control: convergence, robustness and applications* (Lecture Notes series on Control and Information Science, Vol. LNCIS-248). London: Springer.

Markusson, O. (2002). *Model and system inversion with applications in nonlinear system identification and control.* Ph.D. thesis, Kungliga Tekniska Hogskolan, Sweden.

Moore, K. L. (1993). *Iterative learning control for deterministic systems* (Advances in Industrial Control). London: Springer.

Moore, K. L., Chen, Y. Q., Ahn, H.-S. (2006). Iterative learning control: a tutorial and a big picture view. *Proceedings of the 2006 IEEE International Conference on Decision and Control (CDC)*, San Diego, IEEE, pp. 2352–2357.

Phan, M. Q., Longman, R. W., & Moore, K. L. (2000). Unified formulation of linear iterative learning control. *AAS/AIAA Space Flight Mechanics Meeting*, Clearwater Florida, pp. AAA 00–106.

Verwoerd, M. (2004). *Iterative learning control: a critical review.* Ph.D. thesis, University of Twente, Netherlands.

Iterative/Repetitive Learning Control: Learning from Theory, Simulations, and Experiments

Richard W. Longman
Department of Mechanical Engineering, Columbia University The Fu Foundation School of Engineering & Applied Science, New York, NY, USA

Synonyms

Learning control; Repetitive control; Repetitive learning control

Definition

The reader is referred to the separate encyclopedia entry on iterative learning control (ILC), and to Bien and Xu (1998), Moore and Xu (2000), Ahn et al. (2007). Many control system applications involve executing the same command repeatedly, and returning to the same starting point before starting the next repetition of the command, for example, robots in manufacturing operations. When typical feedback control systems are given a specific time varying command, they produce an output similar to the command, but it is not the same. Also, many control systems are subject to the same external disturbances each repetition. ILC aims to eliminate both of these errors by observing the error measured during the previous run, adjusting the command given in this run, aiming to converge to zero tracking error, or to substantially reduce the tracking error. ILC iteratively learns a command that produces zero or small error in a specific task. It does not normally aim to model the system in the learning process. Repetitive learning control, or repetitive control (RC), is similar (Longman 2010, 2000), but applies to control systems that learn to improve their performance while executing a periodic desired trajectory, by observing the error in previous periods and adjusting the command this period. Alternatively, RC can eliminate error produced by periodic external disturbances to a feedback control system, making use of knowledge of the period of the disturbance, but without knowledge of the disturbance itself. ILC differs from RC because the system is repeatedly restarted in ILC, resulting in different mathematics needed for convergence. The learning process in each case is usually based on control theory approaches and can improve the error dramatically in a few iterations, but some literature makes use of other forms of learning, for example, use of neural networks, etc. Because they iterate with real world data, ILC and RC can reach error levels that are substantially better than the error in the models used in designing the control laws.

Theoretical Background

In the evolution of any engineering field there is an interplay between three basic ingredients, three approaches to addressing new problems: (1) The development of a mathematical theory. (2) The use of modeling and computer simulation. (3) Experiments performed in the real world. It is very tempting for people to specialize in one approach and ignore the others. A mathematician may have little interest in realistic simulations, and less interest in conducting experiments. There are engineers that solve all their problems in the laboratory, simply finding a way to make things work in hardware, without knowledge of the underlying theory. This encyclopedia entry discusses the interplay between these approaches in the development of the fields of ILC and RC (Longman 2003). ILC and RC are unusual within engineering because they at least initially ask for convergence to zero tracking error, and ask for this in the real world instead of in a model of the world. And this dramatizes the need to make use of all three approaches. It is claimed that using only one approach can very easily lead to wrong conclusions, very easily make one spend effort at research objectives that do not actually make sense, in spite of the fact that they seem to make sense from the single point view chosen. This is illustrated by documenting the sequence of research objectives of one group of researchers in the field, the author and coworkers, who repeatedly aimed for research objectives that missed the point, and repeatedly found that the experiments defined what the theory should be addressing.

ILC and RC laws can take many forms: They can be based on integral control concepts in the repetition domain, or based on contraction mappings in the time or frequency domain, on indirect adaptive control ideas in the time or repetition domain, on numerical minimizations of functions, on root finding algorithms, etc. The resulting designs can be very effective. Longman (2000) presents results applying ILC to a robot performing a high speed maneuver, and in about 12 iterations for learning, the root mean square (RMS) tracking error was decreased by a factor of 1,000. That is a large number in real world applications. And it is obtained by simply adjusting the command you give an existing control system.

We list a set of six objectives that seem like perfectly logical research objectives from the point of view of mathematical theory of ILC or RC. And then it will be shown that in one way or another, each of these statements is wrong or misguided.

Objective 1: The main research objective should be to prove that my ILC law converges to zero tracking error.

Objective 2: To make the most useful possible ILC law, I should create a law that is guaranteed to converge to zero tracking error for the largest possible class of systems.

Objective 3: For an ILC or RC law to be useful, I must ensure that it is stable.

Objective 4: The best possible ILC or RC laws eliminate all repeating error.

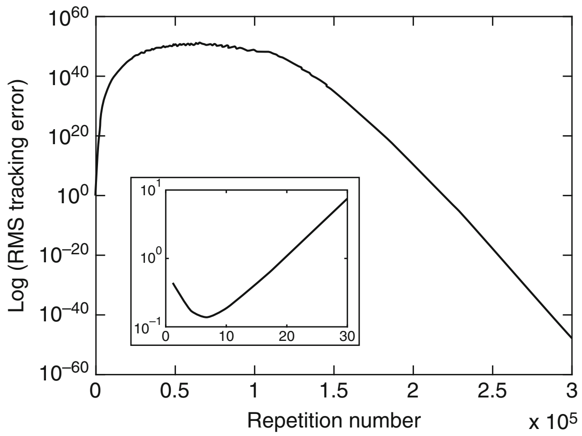
Objective 5: There is no point in iterating in ILC. One should simply make a model of the system, substitute the desired solution, and solve for the required input.

Objective 6: Designing a learning control law that is a contraction mapping should result in a good ILC law.

The Universal ILC Law – Objectives 1 and 2

Aiming for these objectives created an intriguing interplay between mathematical theory, simulations, and experiments. The simplest form of ILC when applied to a robot link, can be described as follows. If at a certain time step in the last repetition the link angle was 2° too low, add 2° to the command this run at the appropriate time step (accounting for the time delay through the system), or more generally, add a learning control gain times 2°. One can prove that for sufficiently small gain of the right sign, with the right time delay, the algorithm will converge to zero tracking error. This result is independent of the system dynamics. One might think that the sufficiently small gain requirement is restrictive, but for the robot experiments, one could use a gain of 90, that is, if the angle was 2° too low one could ask for 180° more and still converge. Knowledge of the right sign can be eliminated by using an alternating sign control law. In fact one can show that the algorithm converges for nonlinear systems fed by a zero order hold, provided they satisfy a piecewise Lipschitz condition, which makes a very large class of nonlinear systems. Hence, the law really is a universal ILC law.

Simulations were performed, simple example simulations, and they showed no real trouble with this law. The alternating sign approach made the learning transients behave better. Robot experiments produced good results for nine iterations, reducing the RMS error by a factor of 50. But then the error started to grow, and the robot made sufficient noise that we had to stop the iterations. We turn to simulations using a model of the robot feedback controllers, and find that the error grows to exponential overflow on the computer. But we have a mathematical proof that it converges to zero error. So we simulate a shorter trajectory and use a slower sample rate and obtain the RMS error history versus repetitions shown in Fig. 1. The mathematical proof was correct. The error grows to 10^{51} radians at repetition 62,132, and then starts to decrease, reaching 10^{-48} radians at repetition 3×10^5. It does converge to zero tracking error. But very few robots can survive for that many repetitions, most robots hit angle limits before reaching 10^{51} radians, and most robot motors cannot produce this angle within the 1 s time allowed in the trajectory. Objective 1 was satisfied, and Objective 2 was satisfied beyond



Iterative/Repetitive Learning Control: Learning from Theory, Simulations, and Experiments. Fig. 1 Simulation of RMS error versus repetition number for the Universal ILC law applied to the control of one robot link

anyone's wildest dreams, but the resulting universal ILC is useless in practice. Experiments indicated that stability was not the issue, having good transients during learning should be the objective.

Who Needs Stability? – Objective 3

The mathematical analysis, simulation, and experiment have some interesting properties when examined from the point of view of stability. (1) The mathematical analyst might not think so, but maybe "instability" can be practical: The exponential overflow during a transient on the way to convergence, certainly represents instability for all practical purposes. But the RMS error decreased by a factor of 50 before the error started to grow. That is a very substantial improvement in tracking accuracy in the real world. So, just turn off the learning after the error goes through this minimum, and you have a very practical "unstable" ILC law. ILC very often has this property of having the error decrease substantially before the error starts to grow (Longman 2000). (2) The experimentalist cannot determine if a system is stable. Certainly, an experimentalist would conclude that the exponential overflow situation was unstable, and he would be right in a practical sense, but mathematically he is wrong, there is a proof of convergence. All one needs is a computer that can handle larger exponents. But on the other hand, experiments run at Xerox Corporation (Longman 2000) using RC showed good behavior for 1,000 periods. Most any experimentalist would conclude the control system was stable. I complained that I knew on theoretical grounds that the RC law must be unstable, because the learning cutoff could not be perfect. When the experiments were run longer, at about period 2,650 one observed an instability starting to appear. This time the experimentalist really got it wrong. (3) Follow-on experiments suggested that an RC law that is unstable in theory and in simulation is stable in experiments in the real world. The experimentalist created a better learning cutoff, and ran 10,000 iterations and no instability appears. The theoretician still thinks it should be unstable. But some doubt appears in our minds, perhaps the frequency components of the error that should go unstable are now so small that it falls below the approximately eight digit accuracy of the analog to digital converters. Then the error could not accumulate in the RC law, and the performance would be stable. This turned out to be the case. This time the experiment cause one to rethink the model used in the theory and the experiments. Without the rethinking, the RC law was unstable in theory and simulation, but stable in the world. The rethinking is resulting in the development of a new method of stabilization of ILC and RC laws. Anomalous stable behavior forced us to look for something left out of our model, something easily overlooked.

Do You Really Want Zero Tracking Error? – Objective 4

Mathematical analysts will want to have convergence to zero error, but experiments can guide us to think that maybe we should not be asking for this. (1) If we use the ILC law above that decreased the error by a factor of 50, and then we turn off the learning process, we are not aiming for zero error. (2) If we just ask that the error in some frequency range get below the last digit of the analog to digital converters, we are not asking for zero tracking error. (3) Experiments at Xerox Corporation on a timing belt drive system did a nearly perfect job of eliminating periodic errors, but the hardware was making so much noise that one feels certain it would wear out very quickly (Longman 2010). One of the large error frequencies was so far above the bandwidth of the control system that the corrective part of the command had to be 11 times as big as the error in order to cancel this error. In order to respect the lifetime of the hardware, the energy consumption of the hardware, and the actuator limitations, one very often should not ask for zero error above some cutoff frequency. This cutoff must be accomplished by use of zero-phase low-pass filters. (4) One of the simplest and most versatile methods of designing ILC or RC achieves the desired good learning transient decay property by making use of a frequency cutoff so one no longer aims for zero error above some frequency (Longman 2000). (5) In most applications one cannot have a good model all the way to Nyquist frequency, but to have good learning transients one needs to know phase response information reasonably accurately for this whole frequency range. People use terms such as parasitic poles or residual modes to describe dynamics at high frequency that are not included in the model used for design, and that are very difficult to identify. One extra pole at high frequency can be enough to destabilize. Hence, one needs to have a frequency cutoff to produce stability robustness to unmodeled high frequency dynamics. On the other hand, the fact that ILC deliberately amplifies signals in the frequency range where your model is wrong, can be used as a method of optimal experiment design for identification purposes, making use of the instability to produce data that can make a better model (Longman 2010).

Do You Need ILC, Why Not Just Invert Your Model? – Objective 5

(1) ILC can do better than whatever model you make. We made a model of the robot controllers, and this model we could invert. Substituting the desired output into the model and solving for the needed input to produce it resulted in a reduction of RMS tracking error by a factor of 10 (Longman 2000). Then using a good ILC algorithm, we continued to reduce the error by another factor of 100. So the final error is two orders of magnitude better than the accuracy of the model used in designing the ILC law. What does all the work of making a model and inverting it do for you? It eliminates the need for the first two iterations out of 12 iterations needed to produce the factor of 1,000. It is easier to do two more iterations. ILC can do better than just inverting the model, because it mixes the two approaches of modeling with experiments – it uses a model, but each repetition is a new experiment collecting data to fix the real world error. (2) Working hard on generating a very good model may not be helpful. There is a substantial literature in ILC that makes use of nonlinear multi-body dynamics models for robots. Our full model of the robot was 72nd order. But the experiments that produced a reduction in RMS error by a factor of 1,000 used a simple linear decoupled model, third order for each link. The resulting final error level was very near the repeatability level of the hardware, which is the limit of what can be learned. So no improvement in the model can result in significant improvement in performance. (3) When the input to systems governed by differential equations goes through a zero order hold in order to apply discrete time control laws, the equivalent discrete time model will have an unstable inverse for pole excesses of three or more, and sufficiently fast sample rates. Therefore, for most systems one cannot invert the model because doing so is unstable. (4) In ILC, the mathematician analyst gets confused about inverting the model, which in this case is a matrix. He knows that the matrix is guaranteed to be full rank, so that the inverse exists. It is lower triangular with nonzero entries on the diagonal. Doing realistic simulations of the feedback control of one link of the robot, for a 1 s trajectory, produces a matrix whose smallest singular value is estimated by extrapolation (the computer is not able to compute this number for a trajectory longer than about 25 time Steps, or one quarter second) to be about 10^{-53}, while the largest is roughly 0.5. No computer is able to compute the inverse of a matrix with the associated condition number, in spite of the fact that the existence of the inverse is guaranteed. The experimentalist testing control laws may not have any idea what is happening, and may not see any trouble, but he does observe that the final error level is not very good. (5) One should not expect to be able to make a model that includes all of the dynamics up to the limiting Nyquist frequency in digital control theory. We know the robot model should contain at least seven vibration modes. We were only able to model two. With some knowledge of phase change through the system, ILC may be able to eliminate errors related to such modes, without actually modeling the modes.

Can Simulation Predict the Performance? – Comment on Objective 6

Simulations are supposed to be a substitute for much more time consuming and expensive experiments. This raises the question, could we have made the same conclusions about what is important in ILC or RC simply by using simulations, without having to perform the experiments cited? (1) The initial simulations of the Universal ILC Law were simple textbook size problems, and no serious issues appeared. So simulations need to be more sophisticated. (2) Would simulations have shown us the instability starting to appear at period 2,650? Not if we do not decide to look for it. The same is true of experiments. (3) Could we ever have learning about stabilization due to finite word length in simulation? Not very likely. We would have to have been smart enough to think the finite word length is something that should be modeled. This is like having to know the answer before you know how to ask the question. (4) In ILC there is a really basic disconnect in simulations verses the real world. We use a model of the world to design the ILC law, then apply it to the world, and find that the error decays to much smaller values than the accuracy level of the model. There is no way one can simulate what will happen in the world, because the performance is based on the real world equations and we do not know them. (5) Most likely one needs to have a frequency cutoff of the learning when applying ILC to the real world. If one wants this cutoff at as high a frequency as possible, there is no way that one can design the ILC law cutoff except by adjusting it in experiments. The cutoff frequency depends on what is wrong with our knowledge of the world, which we do not know. (6) Related to Objective 6, we ran tests on the robot using a Euclidian error norm contraction mapping ILC law. The final error level was disappointing. Of course, one is interested in finding that ILC law that gives the best possible final error level, and this level was worse than for other ILC laws. The final error level observed on a routine simulation of an ILC law has nothing to do with the final error level in the world. It is determined by numerical noise or round off in the computer. In order to study by simulation what this level would be in the world, we would need to know how to characterize the reproducibility level of hardware robot motions, and it is very hard to model what makes the robot do something slightly different each run. The ILC experiments actually got the final error to be below the reproducibility level when measured from day to day, so ILC fixed errors of how differently the robot behaves tomorrow compared to today. How can you model that? One has no idea what makes it different. And it is not just zero mean random effects, but more importantly some systematic changes. (7) And finally, it is very important how you program the equations. The error level of 10^{-48} at repetition 3×10^5 in the simulations for Fig. 1 is the result of using a formula that gives the error in the next repetition as a function of the error this repetition. If instead we programmed the computation of the control law, then applied it to the system equations to get the output, then computed the error, the error computed in the simulations would stop decreasing somewhere in the range of 10^{-12} to 10^{-14}, but the equations used for both types of runs are mathematically equivalent. So one must be careful to program the equations in a manner that mimics the steps used by the real world. Mathematical equivalence is not enough.

The conclusion is that extreme care and a lot of insight would be required to get the simulations to predict real world behavior. Without experiments one is very unlikely to have the needed insights. And even then, one should not expect to be able to come up with a realistic model of how irreproducible the world is, so that one can know the final error level by simulation.

Important Scientific Research and Open Questions

The above discussion dramatizes the importance of formulating the right open questions to address. The author offers no clear guidelines of how to do this, but emphasizes the very basic need to make maximal use of mathematical understanding, modeling and simulation, and experiments in a synergy to guide the development of improved ILC and RC laws. In the above, there are examples where each of these took the lead in pointing out what is important to address. Because ILC and RC at least start by asking for zero error, they push the limits of all approaches. More than in most other fields, ILC makes use of a model to make its design, but its performance, its stability, its learning rate, its final error level are determined very much by what is wrong with one's model. Perhaps the most important open question is then, how does one design ILC to have not the common stability robustness to model error, but instead good learning transient robustness to model error.

Cross-References

► Dynamic Modeling and Analogies
► Experimental Learning Environments
► Iterative Learning Control

► Learning Algorithms
► Mathematical Models/Theories of Learning
► Simulation-based Learning

References

Ahn, H.-S., Chen, Y., & Moore, K. L. (2007). Iterative learning control: brief survey and categorization. *IEEE Transactions on Systems, Man, and Cybernetics, Part-C, 37*, 1099–1122.

Bien, Z., & Xu, J.-X. (Eds.). (1998). *Iterative learning control: analysis, design, integration and applications.* Boston: Kluwer.

Longman, R. W. (2000). Iterative learning control and repetitive control for engineering practice. *International Journal of Control, 73*(10), 930–954.

Longman, R. W. (2003). On the interaction between theory, experiments, and simulation in developing practical learning control algorithms. *International Journal of Applied Mathematics and Computer Science, 13*(1), 101–111.

Longman, R. W. (2010). On the theory and design of linear repetitive control systems. *European Journal of Control, 16*(5), 447–496.

Moore, K., & Xu, J.-X. (Guest Eds.) (2000). Special issue on iterative learning control. *International Journal of Control, 73*(10): 1–999.

I