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Machiavellian Intelligence Hypothesis

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Synonyms

Social brain, Social intelligence

Definition

Elaborated originally in the study of primates, the "Machiavellian intelligence hypothesis" (Byrne and Whiten 1988, 1997) is that the large brains of humans grew over the millennia because of intense social competition for reproduction. Competitors evolved ever more complex strategies and tactics to achieve social dominance with consequent reproductive success. This hypothesis interprets even seemingly altruistic acts in primates as self-interested cunning.

Theoretical Background

The Hypothesis explains why primates have such large brains, far larger than that of other beasts of a similar size, far larger than necessary for most of their day-to-day lives. The brain size is puzzling because brains are expensive and fragile. They consume a great deal of energy; they are vulnerable to injury. What enlarged brain size brings is the capacity to interact socially and to remember previous social encounters (Humphrey 1976). Brains allow primates to learn how to interact socially and for that learning to evolve. The Machiavellian Intelligence Hypothesis is that large brains enabled primates to establish social relations based in part on the shared past. They learn from their interactions with each other and they retain that knowledge. We humans come after thousands of generations of that evolution in our forerunners.

Sometimes the Machiavellian intelligence hypothesis is called the social brain or social intelligence. The association with Niccolò Machiavelli, an early sixteenth century Italian official and thinker is but literary. Machiavelli made no study of primates nor of brain evolution. However, Frans de Waal in his *Chimpanzee politics* (1982) quotes Machiavelli's works. De Waals found some of Machiavelli's insights into the capacity of some Renaissance politicians to operate on several levels at once – altruistic and selfish, devout and nationalistic, grasping and strategic at the same time – captured some of the interaction among the chimps he observed. The name stuck.

Important Scientific Research and Open Questions

The term Machiavellian intelligence is now used to explain patterns of behavior far beyond both humans and primates. Dolphins, elephants, and fish, among other creatures, have had the Machiavellian Intelligence Hypothesis applied to their behavior (Bshary 2006). In addition, the term is sometimes found in the study of artificial intelligence (Gordon 2001). A search on the Web of Science today will harvest many references across evolutionary biology, primate studies, and artificial intelligence.

Cross-References

- ► Animal Culture
- ► Animal Learning and Intelligence
- ► Artificial Intelligence
- ► Goodall, Jane
- ► Human–Robot Interaction

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Machine Inductive Inference

► Formal Learning Theory

Machine Learning

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Synonyms

Learning in computers

Definition

Machine learning (ML) is a scientific discipline that concerns developing learning capabilities in computer systems. Machine learning is one of central areas of Artificial Intelligence (AI). It is an interdisciplinary area that combines results from statistics, logic, robotics, computer science, computational intelligence, pattern recognition, data mining, cognitive science, and more.

A computer system learns if it improves its performance or knowledge due to experience, or if it adapts to a changing environment. The experience can be of the system that learns, or can be provided from outside, for example, in the form of data from which the system learns. Although the majority of machine learning methods concern learning from data, this is not the only available form of learning. Results of machine learning are in the form of knowledge or models (functions) representing what has been learned, and are most often used to make predictions about the future or unknown cases/situations.

The idea of machine learning has been present in AI since its beginning in the 1950s. In 1980, machine learning emerged as a separate field during the first workshop organized by Ryszard. S. Michalski, Jaime Carbonell, and Tom Mitchell at Carnegie Mellon-University. The workshop was followed by the first book on machine learning, published in 1983 (Michalski et al. 1983). Since then the field has systematically grown and several subfields have been created.

Theoretical Background

Machine learning methods can be classified by the use of instructor, forms of knowledge and data used, and ways in which the system learns. Most commonly, machine learning methods are classified as:

- *Supervised learning* (a.k.a. learning with instructor) in which data consisting of both input (independent) and output (dependent) variables are provided. Two major forms of supervised learning are classification and regression learning.
- *Unsupervised learning* (a.k.a. learning without instructor) in which the goal is to identify an underlying structure of the data without explicitly defined output. Two typical forms of unsupervised learning are clustering and association rule learning.
- *Reinforcement learning* in which the goal is to discover a sequence of operations that lead to a solution that maximizes "reward."

Combinations of these classes of methods, such as semi-supervised learning, are also widely studied.

Important Scientific Research and Open Questions

Currently, the main research directions in machine learning include development of new algorithms, theoretical analysis learning methods, and applications of the methods to real world and artificial problems. In machine learning, the following criteria are considered when developing new methods:

- *Accuracy.* Created models have to provide reliable predictions, which in most cases is their main function. Therefore, machine learning methods need to accurately map input into these models.
- *Representation.* Models can be represented in multiple forms such as equations, graphical models, rules, decision trees, sets of representative examples,

and neural networks. Choice of representation is known to affect accuracy of the models, as well as their understandability by humans.

- *Acceptability.* Models need to be accepted by potential users. While partially related to transparency, acceptability requires that the models don't contradict the knowledge of existing experts or are otherwise "reasonable."
- *Efficiency.* Both model induction and model application algorithms need to be efficient. This is particularly important for machine learning methods that deal with very large datasets.

Cross-References

▶ Learning Algorithms
▶ Model-Based Imitation Learning
▶ Multi-robot Concurrent Learning
▶ Reinforcement Learning
▶ Supervised Learning
▶ Unsupervised Learning

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Machine Learning in Robots

▶ Robot Learning Via Human–Robot Interaction: The Future of Computer Programming

Machine Learning of Natural Language

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Synonyms

Computational natural language learning

Definition

Machine learning of natural language refers to attempts to acquire models of human language by automated means, typically through the analysis of human language artifacts. While work on this problem may be informed by theories of human language acquisition, its motivation is less the explication of *human language learning* than the construction of computer systems that demonstrate competence in various functional aspects of natural language. Progress is typically measured by means of quantitative tests involving gold-standard datasets designed to express a particular requisite capability, rather than by appeal to psychological or cognitive studies of human language use. Here, we are interested only in features of language common to its two primary vehicles, *speech* and *text*; in particular, the problem of machine learning from speech introduces a variety of engineering and scientific challenges that are beyond the scope of this entry.

Theoretical Background

Work on machine learning of natural language draws heavily on research in general machine learning and computational statistics, inheriting much of their theoretical infrastructure. A core function of language is the transmission of information, which is the focus of *information theory*, a theoretical framework fundamental to machine learning approaches to computational linguistics. Information theory is a branch of probability theory covering the communication of information, framed as messages conveyed by some overt encoding. For example, information theory underpins modern telecommunications, where it describes how data may be transmitted reliably and efficiently as a sequence of bits. Human language may be viewed as another method for encoding information for transmission, and although it exhibits richer structure, greater ambiguity, and more redundancy than the bit sequences that constitute cell phone communications, discovery of language's functional characteristics is nevertheless susceptible to the same information-theoretic techniques. More generally, *probability theory* and *Bayesian statistics* are fundamental to machine learning and its application to human language. Many language phenomena are modeled as the output of a hypothetical *generative model*, enabling the discovery of latent structure without overt annotations of the relevant phenomena. Specific kinds of generative model that are commonly used in computational language learning include *naïve Bayes* models, *hidden Markov models*, and *Bayesian networks*.

A core focus of machine learning, both in general and in its application to human language, is classification. Many problems of computational linguistics can be framed as an assignment of observed phenomena into one or more prior categories, which are often suggested by linguistic theory. A simple example, and one of considerable practical importance, is deciding what parts of speech to assign to each of the words in a sentence, a process referred to as part-of-speech "tagging." Whereas the individual classifications required by part-of-speech tagging – the assignment of a part of speech to each word in the input – can be performed in isolation, intuition suggests and research demonstrates that classifying in a coordinated fashion yields greater accuracy. Computational linguistics is a rich source of classification problems like this, in which the desired output is not an individual classification, but a collection of coordinated classifications combined in a structured object such as a sequence or a graph. These are problems of *structured classification*, an area that has been the focus of recent theoretical and algorithmic work in machine learning.

Classification problems arising from the modeling of natural language are often characterized by a wealth of sparsely instantiated features. For example, in part-of-speech tagging, we might define a Boolean feature that is true when the current word is "encyclopedia," a feature that will almost always be false in typical use. Recent work in machine learning offers a range of algorithms based on a geometrical understanding of the classification problem that are robust to problems characterized by high dimensionality and an abundance of marginally relevant features. Such algorithms arising from *large margin theory* include the support vector machine, a family of algorithms that has advanced the state of the art in many problems of computational linguistics.

Much work in the unsupervised acquisition of syntactic or semantic knowledge is motivated by a principle first enunciated by Harris (1968). The *distributional hypothesis* (also called the *substitutability hypothesis*) was originally advanced as an explanation of the ability of human language learners to infer the meaning and appropriate use of previously unknown words. Under this hypothesis, words are characterized by features of the linguistic context in which they are used, and learners acquire new words by comparing the unknown words' contextual distributions with those of known words. A number of computational embodiments of this principle have been applied to the analysis of large text corpora, leading to the automatic acquisition of various aspects of linguistic competency, including syntactic functional categories (parts of speech), elements of language morphology, grammar rules, and synonym groups.

Important Scientific Research and Open Questions

Many specific challenges of computational linguistics are currently best addressed by approaches predicated in whole or in part on machine learning. On some problems, the resulting models achieve near-human accuracy. For example, machine learning approaches have been proposed that perform part-of-speech tagging with accuracy over 95% on reference corpora derived from newswire articles. All such approaches involve *supervised learning*; models are trained on large volumes of text in which individual words have been given labels that reflect human judgments about their parts of speech. On most problems where this methodology is employed, accuracy increases in an apparently asymptotic fashion as the amount of labeled data is increased. The height of the asymptote and the steepness of the "learning curve" depend on the difficulty of the problem. Accuracy in English part-of-speech tagging may be adequate for many applications that require it, but on harder problems, such as syntactic parsing and machine translation, but achieving comparable accuracies on harder problems, such as syntactic parsing and machine translation, may require prohibitive amounts of labeled data. Circumventing this "human bottleneck" is a central focus of much current research in computational linguistics. Given the relative abundance of human language data in the current computing environment, much effort is directed to the design of *semi-supervised* learning algorithms, which exploit large volumes of unlabeled data in conjunction with a relatively small amount of labeled data.

The success of algorithms in this class has intensified a debate within computational linguistics between what we might call "deep" and "shallow" approaches to the modeling of human language. Deep approaches are informed more thoroughly by linguistic theory, attempting to address specific problems with algorithms that reflect faithfully the linguistic and cognitive structures that are presumed to be relevant to them, whereas shallow approaches target the functional demands of the problem directly, employing whatever techniques can be shown to optimize performance. For example, a deep approach to machine translation attempts to construct a semantic representation of the input, and to derive the translation into another language from this intermediate representation. A shallow approach, in contrast, maps directly from the words or phrases in one language to those in the other, using large word and phrase tables derived from "parallel corpora," in which sentences from the respective languages have been aligned. Some proponents of statistical machine translation, which is at the forefront of current work on the problem, argue that only the lack of training data in adequate volumes prevents computers from achieving human accuracy for most practical applications. The success of such "large-data" approaches has been replicated on other problems, leading some to argue against deep, theory-driven approaches and in favor of research into techniques that can exploit the current abundance of language data (Halevy et al. 2009).

Of course, human learners acquire language without any explicit labeling of the relevant phenomena, an observation that motivates research into the purely *unsupervised* acquisition of language competency. Given nothing but a (typically large) corpus of text, the objective is to derive linguistic knowledge enabling the resulting models to perform well in the same tests used to evaluate supervised approaches. Although evaluated accuracy lags behind that of supervised approaches, successful learning has been demonstrated on a range of problems. In a work influential in both machine translation and speech modeling, Brown et al. (1992) showed that an information-theoretic clustering of words according to their context distributions recovered latent syntactic and semantic categories. Klein (2005) built on these insights, employing a generative model framework to induce grammatical rules directly from unlabeled corpora, demonstrating effective learning of syntax on multiple languages. Dumais demonstrated the recovery of lexical semantics, at least those aspects of semantics required to advance the state of the art in information retrieval, using singular value decomposition of a matrix of documents and their constituent words. In an influential paper, Landauer and Dumais (1997) argue that the learning curve associated with "latent semantic analysis" exhibits some of the characteristics of the human language learner over the years in which language acquisition is most active.

All such solutions share two limitations, one a practical concern that is a focus of active research, the other a more fundamental problem. First, although machine learning models can address specific problems of computational linguistics very effectively, this effectiveness is always restricted in greater or lesser degree to the domain from which training data is drawn. This problem of *domain specificity* may limit the usefulness of a part-of-speech tagger trained on newswire text when it is applied to other domains or less formal genres, such as e-mail or chat. Second, and more critically, in contrast with the human learner, the machine learner's acquisition of language knowledge is generally divorced from the uses for which the language was originally intended. The effective incorporation of context when learning or using language remains an enduring challenge to the machine learning of natural language, as to the larger endeavor of computational linguistics.

Cross-References

► Bayesian Learning
► Language Acquisition and Development
► Probability Theory in Machine Learning
► Supervised Learning

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Macro Actions in Robot Learning

► Motor Schemas in Robot Learning

Magical Thinking and Learning

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Synonyms

Autistic thinking; Fantastical thinking; Wishful thinking

Definition

Magical thinking (MT) comprises the events and entities that violate known physical principles and conventions. Such events and entities may include talking animals, inanimate objects that turn into humans or animals, objects that appear from thin air or instantly turn into other objects, flying horses, dragons, or the idea that one's thoughts can produce direct physical effects on inanimate objects. Unlike *ordinary fantasy* (i.e., a child having an imaginary friend or dreaming that his or her mum buys a desired toy), magical thinking is unfolding whenever a person is involved in some kind of mental processing of supernatural events (i.e., through seeing magical events in a dream, reading a book, or watching a film with magical content).

Theoretical Background

Psychologists have long noticed that young children in Western cultures remain open to the possibility that magic is real. Jean Piaget (1929–1971) provided multiple examples of young children's magical behavior (e.g., one boy believed that by saying their names he could make gorgeous birds and butterflies in his father's illustrated manual "to come to life and fly out of the book, leaving holes behind them") (p. 135). Harris et al. (1991) asked children aged 4 and 6 years to pretend that there was a creature (a rabbit or a monster) in an empty box. When left alone, some children behaved as if the pretended creature was really in the box. In another study, children aged 4, 5, and 6 years were presented with a magic box that could turn pictures into real objects if a magic spell was cast (Subbotsky 1985). When asked if such things can happen in real life, almost all children denied this. But when the experimenter went out of the room "to make a phone call," up to 90% of children tried to magically convert pictures into objects and were bitterly disappointed when this did not happen. Another experiment targeted children's belief in the magical ways of moving in space and time. Initially, most preschoolers denied the possibility of moving through walls or going back in time. However, when shown "magical" effects which made these events seem to have happened, the majority of 4- and 5-year-olds and some 6-year-olds tried to pass their hand through a glass wall (in order to obtain an attractive object) and refused to drink "magic" water (fearing they would become younger again), thereby revealing their belief in the potentially unusual properties of space and time in everyday reality (Subbotsky 1994).

In contrast to earlier theories that viewed MT as a phenomenon specific to early childhood (i.e., Piaget), recent studies have shown that MT persists in children of older ages and, albeit to a smaller extent, adults (Nemeroff and Rozin 2000; Subbotsky 2010). The issue that arises in this context is whether involvement in MT is a byproduct of cognitive development that occurs coincidentally and occasionally is used for entertainment, or whether it is a necessary stage of development and has to do with cognition, learning, and communication.

Important Scientific Research and Open Questions

Research on MT suggests that children who are passively involved in MT can learn to be more creative at solving divergent thinking tasks. Subbotsky et al. (2010) showed 4- and 6-year-old children a film with either magical or non-magical theme, and then tested on their ability to solve tasks on divergent thinking (i.e., problems that do not have only one correct answer, but allow for a variety of alternative solution). Results indicated that the mean scores of children shown the magical film were significantly higher than that of children watching the non-magical film on the majority of subsequent creativity tests, for both age groups. This trend was also found for 6-year-olds' drawings of impossible items. These results were replicated successfully with 8-year-old children.

There is also evidence that involvement in MT can enhance children's ability to discriminate between fantasy and reality. Distinguishing fantasy from reality is important because it mediates the effect of mass media on children and adults' subsequent behavior. It has been shown, for instance, that children who were aware that a violent film clip was real later reacted more aggressively than children who believed that the film was a fantasy; similar mediating effect the fantasy–reality distinction ability may have on children's vulnerability to violent video and computer games (Comstock and Scharrer 2006). Subbotsky and Slater (2011) examined whether children who watched a film with highly magical effects learn to discriminate between ordinary and fantastic visual displays, through priming or (and) association. Six- and nine-year-old children were shown a film with either a magical or non-magical theme and were asked to discriminate between ordinary and fantastic visual displays on a computer screen. Results indicated that the mean discrimination scores of children shown the magical film was significantly higher than that of children watching the non-magical film for both age groups.

In memory domain, Principe and Smith (2008) reported that 5- and 6-year-olds who strongly believed in a fantastic entity – the Tooth Fairy – gave different reports of their most recent primary tooth loss from those who believed in the Tooth Fairy to a lesser extent. Not only were believers' reports more complex and voluminous than those of non-believers, but they also recollected more supernatural occurrences, including actually hearing or seeing the Tooth Fairy. This study showed that belief in a magical entity could affect cognitive processes, by creating *false memories* of events that contradict known physical laws. Another study (Subbotsky and Matthews 2010) examined if proneness toward magical thinking facilitates memories of fictional events, such as commercial television advertisements with magical effects (i.e., talking animals, inanimate objects that turn into humans, objects that appear from thin air or instantly turn into other objects). Adolescents and adults viewed two films containing television commercials and then attempted to recall and recognize the films' characters, events, and advertised products. Film 1 included magical effects, and Film 2 did not include such effects. An immediate recognition test revealed that both adolescents, but not adults, showed significantly better recognition for the products advertised in the magical film than for the products advertised in the non-magical film. When the recognition test was repeated in 2 weeks, adults too recognized products advertised in a magical film better than products advertized in a non-magical film.

Altogether, the findings modify some aspects of our understanding of children's cognitive development and have implications for learning. Teachers sometimes use magical content in the classroom to enhance interest and increase engagement in the material. The reported research suggested that books and videos about magic might serve to expand children's imagination and help them to think more creatively. Viewing films with magical content can also help children learn the distinction between fantasy and reality. Finally, MT affects memories in children and adolescents, by enhancing false memories in children and facilitating adolescents and adults' real memories for magical effects in advertising.

Cross-References

► Human Cognition and Learning
► Imagery and Learning
► Imagination Effect
► Imaginative Learning

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Maintenance Learning

► Reproductive Learning

Maladaptive Behavior

► Psychopathology of Repeated (Animal) Aggression

Maladaptive Schemas in Patients with or Without Personality Disorders

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Synonyms

Core beliefs; Core constructs

Definitions

In general, a schema can be defined as an abstraction of a concept that is induced from past experiences and guides the organization and appraisal of incoming information.

Maladaptive schemas are enduring, rigid, exaggerated, and often, at least partially, preconscious beliefs regarding the self and relationships with others causing psychological distress and interpersonal problems.

According to the American Psychiatric Association (2000), a personality disorder can be described as a stable, pervasive, and inflexible pattern of inner experience and behavior, emerging in adolescence or early adulthood, deviating markedly from the expectations of the individual's culture, and leading to distress or impairment. Ten specific personality disorders are distinguished: paranoid, schizoid, schizotypal, antisocial, borderline, histrionic, narcissistic, avoidant, dependent, and obsessive-compulsive personality disorder.

Cognitive therapy is an active, collaborative, time-limited, and empirical-based psychological treatment approach focusing on the role of information processing in the development and maintenance of psychological disorders.

Theoretical Background

The concept of maladaptive schemas has been part of cognitive therapy since its first formulations in the 1960s. It received a prominent role when cognitive therapies for personality disorders were developed in the 1980s and 1990s. Traditional short-term cognitive therapy focused on psychological problems that manifest themselves primarily in symptoms (e.g., depression or anxiety), but the treatment of personality disorders requires that the personality of the patient or his or her basic patterns of construing the intra- or interpersonal world are addressed. In cognitive therapy, the building block of the individual's personality is his or her characteristic schemas and schema-driven behaviors. Therefore, maladaptive schemas are considered to be at the core of personality disorders and are the target of treatment in cognitive therapies of personality disorders.

Beck and coworkers (Beck et al. 2004) have described all ten personality disorder categories in terms of typical maladaptive schemas and methods and techniques for their modification. An alternative cognitive treatment approach for personality disorders is Jeffrey Young's schema therapy. Young and colleagues (Young et al. 2003) have elaborated on the schema concept and proposed a subset of schemas, so-called Early Maladaptive Schemas (EMSs). EMSs are defined as broad themes, consisting of beliefs, memories, emotions, and body sensations regarding oneself and one's relationships with others. Thus, EMSs refer to more complex structures than just cognitions or thoughts, but embody a coherent pattern of cognition, emotion, and behavioral disposition. EMSs operate on the deepest level of cognition and emotion, and are generally outside of awareness.

It is assumed that EMSs are formed during childhood and adolescence. According to Young et al. (2003), the main cause for developing an EMS is that universal psychological needs of the child are repeatedly frustrated. Psychological needs of every child involve, for example, secure attachments to others, autonomy, realistic limits, spontaneity, and freedom to express valid feelings. When these needs are not met because of ongoing adverse experiences with family members or, later in life, peers, the child is at risk to develop an EMS. Thus, an EMS is the result of ongoing negative social interactions, for example, mistreatment and traumatization. On the other hand, overprotection may also contribute to the formation of an EMS. EMSs reflect the child's attempts to make sense of these experiences and to adapt to its adverse environment. Often, EMSs are perpetuated later in life even if the circumstances have changed. The EMSs have become a part of the individual's identity, and the individual behaves and interprets situations in a way that confirms the schema. Therefore, EMSs are difficult to change. Based on this developmental model and clinical experience, Young and colleagues have developed a list of EMSs that cross-cuts psychiatric diagnoses and currently comprises 18 EMSs. For example, the abandonment schema involves the expectation that close others are unstable or unpredictable and that one finally is abandoned. The emotional inhibition schema refers to the belief that one must inhibit spontaneous feelings in order to avoid negative consequences.

EMSs are thought to be the result of negative interaction with attachment figures. At the same time, EMSs hamper the child's capacity to form secure attachments to others leading to longstanding difficulties in establishing satisfying close relationships with others. Since EMSs are so closely tied to the individual's identity and personality, it is assumed that EMSs are at the core of deviant and dysfunctional personality traits and personality disorders. In addition to these problems, EMSs may underlie other psychological problems, such as recurrent depression, anxiety, or substance abuse.

An EMS becomes activated in situations relevant to the schema and is associated with a high level of negative emotion. The individual may respond to an activated EMS with a characteristic coping style. Young et al. (2003) distinguish between surrendering (give in), avoidance (avoid the activation of the schema), or overcompensation (acting as if the opposite of the schema was true). For example, an individual with a defectiveness/shame schema (the belief that one is fundamental defective and therefore inherently unlovable) may surrender to it by choosing partners that are critical and rejecting, avoid it by not expressing own feelings and thoughts, or overcompensate by pretending to be perfect and criticizing others. Generally, the individual is not aware of his or her coping behavior.

EMSs are trait-like in that they are proposed to be stable over time, but an EMS is not necessarily activated at every moment. In order to describe a patient's current state, the concept of modes has been introduced. Schema modes are those maladaptive schemas and coping behaviors that are currently operating.

For the assessment of EMSs in adult psychiatric patients, self-report questionnaires have been developed that cover the EMSs Young et al. (2003) have proposed, but the clinician also looks for recurrent themes in the patient's life history and behavior in the therapeutic relationship.

Empirical research on the relationships between EMSs and personality disorders has shown that patients with personality disorders score higher on almost all schemas than patients without personality disorders. Studies have also investigated the relationships between specific EMSs and personality disorder categories. However, consistent patterns of relationships have not emerged yet.

Important Scientific Research and Open Questions

The research body regarding maladaptive schemas has been rapidly growing in the last years. Associations between EMSs and a broad range of psychiatric diagnoses and psychological problems have been reported. It has also been shown that individuals who have been physically or emotionally abused in childhood or remember their parents' rearing style as cold and rejecting also report a higher level of maladaptive schemas. Thus, the maladaptive character of these schemas has been demonstrated. Further, EMSs have shown to be moderately stable in patients over a period up to 9 years. Nevertheless, important questions remain to be answered. First of all, the development and course of maladaptive schemas in childhood and adolescence need much more research. Can EMSs be identified in childhood? How do temperamental and environmental factors interact in the formation of schemas? Recently, measures of EMSs for children have been developed. These measures may help to investigate the development, course, and stability of EMSs from childhood to adulthood. Further, the assessment of EMSs is an ongoing challenge. Usually, self-report questionnaires are used to assess EMSs in individuals. However, EMSs are, by definition, partly preconscious, that is, the person may not be aware of having a particular EMS and therefore not report it in a self-report inventory. There is a need to develop alternatives that trespasses the shortcomings of self-report questionnaires.

Cross-References

► Early Maladaptive Schemas: The Moderating Effects of Optimism
► Emotional Schema(s)
► Schema(s)
► Schema Development

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Male and Female Learning Outcomes

► Gendered Perceptions of Learning

Management Learning

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Synonyms

Leadership learning

Definition

Management learning is about what it says on the bottle: the learning of management (as distinct from the management of learning which may be equally important and interesting). A definition, based on Burgoyne and Reynolds (Burgoyne and Reynolds 1997), is: the learning of management and leadership as the ability to organize organizations, the facilitation and evaluation of this, and the assistance of managers and leaders to progress through being effective (able to do without knowing how they do it) to being reflective (knowing how they do it) to being critically reflective (thinking about the strength and weaknesses of, and alternatives to, their existing knowledge that underpins their actions).

Theoretical Background

"Management" can be taken as an abstract function, an activity, a faction in organizational settings, and also refer to managers in the individual and collective sense. It can be thought of as the "organization of organization," and to include what is also referred to, in the Anglo-American context at least, as administration, leadership, execution (as in the executive role), and direction (as in what directors do). It has a relationship to entrepreneurship as well with some similar and some differing elements.

The meanings (in use) of these terms have shifted around with time. In the 1960s and 1970s the preferred term was administration, now largely gone but living on in the MBA (Masters in Business Administration). Then there was the debate between administration and management, casting the former as relatively routine and the latter as facing unstructured, non-routing problems. More recently this distinction has been made under the headings of management and leadership, and more recently still within leadership in the distinction between transactional and transformational leadership.

Cross culturally different terms are in use. In French "gestion" is something like operational management, "dirigion" strategic management, or leadership. Leadership is difficult to discuss in German since the word is "fuehrer," which still has world war two connotations. In America the term "Chief Executive Officer" (CEO) is used whereas the British term is "Managing Director," though CEO is spreading worldwide.

The learning part of management learning is about learning in respect to management in all the above senses.

It begs the question of what, if anything, is special about learning management as opposed to learning anything else or learning in general. There is, perhaps, the prior question of whether management can be learnt at all, this debate being most often carried out in the context of leadership and the question of whether leaders are born or made.

On the latter, there are many views, but one of the most plausible is from evolutionary psychology that argues that the *will* to lead is largely innate, but that the *ability* to do it well is learnable (Nicholson 2000). There is also the related debate as to whether it is learnable (e.g., from experience), or teachable, with a middle ground here around the facilitation of "natural" learning through processes like coaching, mentoring, and action learning (sometimes called the "context sensitive" methods).

If there is anything special about learning *management*, and I think there is, it is to do with the unstructured nature of management challenges, that it faces "wicked" rather than "tame" problems (though this debate is contained in debates about what management is, see above). This is a recurring theme in the literature, to be found in Simon's distinction between programmed and unprogrammed work (Simon 1957), Burns and Stalker's distinction between mechanistic and organic (Burns and Stalker 1961), the distinction between "P" (programmed knowledge) and "Q" (questioning knowledge) in action learning (Revans 1983), more recently in distinctions made between management and leadership (Bennis 1989), then within leadership in the form of the distinction between transactional and transformational leadership (Bass et al. 1996), and finally in the distinction between order and chaos in complexity theory (Stacey 1992).

Management learning in the collective rather than individual form of management (thus developing social rather than human capital) suggests organizational learning, i.e., the notion that organizations, as bounded entities, can learn collectively. Learning organization and organizational learning is an important area within management learning (Senge 1990; Pedler et al. 1996).

The learning aspect of management can be both naturally occurring or deliberately facilitated (Burgoyne and Hodgson 1983) and understood in terms of theories, models, principles, and practices directed at facilitating learning. I have summarized 14 schools of thought on learning, in terms of types of theory (Burgoyne 2002).

Two important institutional landmarks to do with management learning are what is now the Department of Management Learning and Leadership, which has evolved from a research unit founded in 1974 to develop the practice and practitioners of management education, and what is now the academic journal called Management Learning.

The department has run a part time MA, now the MA in Management Learning and Leadership for 30 years, for experienced practitioners of management, leadership, and organization development, and for developmental leaders who want to do it as an alternative to the MBA.

The journal has evolved from a more practitioner-oriented journal called Management Education and Development, which was the journal of the Association of Management Education and Development. This was an association of management educators, corporate trainers, and consultants, which has subsequently lost ground to the British Academy of Management, the more academically oriented body.

Important Scientific Research and Open Questions

Can management learning provide an overarching and integrating framework for the whole of management, organization, and business studies? Can it provide, for the first time, through a critically realist based methodological approach, a professionally oriented and scientifically based approach to management, leadership, and organization? Critical realism takes the world to be an open system with emergent properties rather than a determinist machine as the positivists do or just a sea of cultural meaning as the post modernists and extreme social constructionists do. Managers and leaders deal with systems with human and nonhuman elements. The physical, zoological and biological, psychological, and social worlds get increasingly complex and unpredictable as one progresses through these, and managers and leaders deal with systems from all points on this spectrum.

Cross-References

- ► Absorptive Capacity and Organizational Learning
- ► Acquiring Organizational Learning Norms
- ► Evaluation of Management, Leadership, and Organization Development
- ► Organizational Change and Learning
- ► The Learning Organization

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Managing Stress

► Stress Management

Mandatory Education

► Compulsory Education and Learning

Manipulative Practice

► Drill and Practice in Learning (and Beyond)

Many Aspects of Anticipation

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Synonyms

Anticipatory behavior; Expectation; Forecast

Definition

Anticipation refers to the capacity of a system to take its decisions in the present according to forecasts about something that may eventually happen at a later moment.

Theoretical Background

Behaving in an anticipatory way means adjusting present behavior in order to address future problems. In other words, an anticipatory system takes its decisions in the present according to forecasts about something that may eventually happen at a later moment (Rosen 1985, p. 341, see Louie 2010 for an introduction to Rosen's ideas). The main surprise embedded in the theory of anticipation is that anticipation is a widespread phenomenon present in and characterizing all types of systems. Life in all its varieties is anticipatory, the brain works in an anticipatory way, the mind is obviously anticipatory, society and its structures are anticipatory, even nonliving or nonbiological systems can be anticipatory.

As soon as one collects data on anticipation, the real surprise is that over the past century many scholars from many different disciplines and fields have worked on anticipation. The unwelcome finding is that nobody has to date systematically collected and compared the various proposals (see Poli 2010 for a first survey and Nadin 2010 for an extensive, commented bibliography on anticipation). The following is but a cursory presentation of the research on anticipation in various fields.

Philosophy. Husserl, Mead, and Bloch have worked on various aspects of anticipation. Husserl views anticipation as one of the three components of the most basic structure of consciousness: the specious present. For Husserl, what is actually given is always surrounded by a double halo comprising what has just happened (retention: strictly speaking, something has gone but its effects are still active) and what is going to happen (pretension or anticipation: even if we do not know what is going to happen, we naturally – i.e., automatically – develop expectations, which may eventually be confirmed or disconfirmed).

Mead embedded anticipation in what he called "conversation of gestures," where two organisms show each other the actions that they are going to perform. In this way, the other organism can prepare itself before the actual execution of the action. Finally, Bloch developed what I call an "encyclopedia of the categories of the future" based on the idea that entities are only partially determined because some of their aspects are still hidden or latent. The difference between being hidden and being latent can be clarified as follows: Hidden components are there, waiting for triggers to activate them. On the other hand, latent components do not exist at all in the entity's actual state. Latent components relate to incompletely present conditions and aspects. Their incompleteness may be ascribed either to still maturing conditions or to new conditions that may subsequently arise (Poli 2009).

Biology. Over the past few decades, an enormous amount of experimental evidence in favor of anticipation as a behavioral feature has been accumulated. Studies on anticipation in animals have moved through two main phases of development. The first phase was centered on Tolman's "expectancies" or *latent learning*, i.e., learning of environmental structures despite the absence of reinforcement. The studies conducted by Tolman had little impact, however, and the study of anticipatory behavior in animals started to spread only in the 1980s.

Brain studies. Neurons and more complex brain structures appear to contain what have been called "internal models," whose main task is to guide the brain in its decision-making activities (be these the firing of neurons or something more complex for higher-order structures).

Psychology. Anticipation is an old friend of psychologists. Herbart claimed that anticipations of sensory effects not only precede but also determine voluntary movements. This thesis, known as the Ideo-Motor Principle (IMP), runs contrary to the claim that psychic processes in general are determined by stimuli (i.e., it is at odds with both behaviorism and most of current cognitive psychology). After the prelude represented by Herbart, studies on anticipation in psychology have been conducted only very recently, providing evidence of distinct forms of anticipation in learning, attention, object recognition, and many other cognitive activities. These studies show that behavior is more goal oriented than stimulus driven. In other words, they show that there are robust reasons for challenging one of the main assumptions of cognitive science, namely that stimuli come first. The contemporary version of IMP claims instead that ambient interactions reinforce *anticipated* outcomes. Behavioral and cognitive schemata – be they pre-given or acquired – shape the way in which organisms look at the environment. For this reason they are anticipatory.

Social sciences. Schutz argued that we simultaneously live in different contexts of meaning, with different temporal dimensions, at different levels of familiarity. Actions are typically framed by two types of opposition: the opposition between my actions and your actions and the opposition between future and past actions. Future actions are interpreted according to an "in-order-to" structure, while past actions are interpreted according to a "because" structure. In-order-to motives are components of the action: They shape the action from within. By contrast, because-motives require reflective acts upon already performed actions. This structure helps explain why we perceive actions as free according to in-order-to-motives and as determined according to because-motives. Actions are always elements of wider projects, which in their turn rely on various stocks of knowledge. One of the most familiar components of knowledge is the stock of typical expectations, which may become actual in typical circumstances and predetermine typical reactions.

Futures studies. Studies of futures fall under two main assumptions: (1) that the future is at least partly governed by the past, and (2) that the future can be better confronted by opening our minds and learning to consider different viewpoints. According to (1) the forces which have shaped past and present situations will still be valid as the situation under consideration unfolds; (2) instead considers the problem of preparing for the unforeseeable novelties awaiting us in the future. Learning about widely different outcomes is the issue in this case: One must be ready to anticipate possibly unfamiliar or alien scenarios.

Important Scientific Research and Open Questions

Even if most of the details concerning anticipation are still unknown, the following partial observations summarize the current state of knowledge.

Anticipation comes in many different guises. The simplest distinction is between explicit and implicit anticipation. Explicit anticipations are those of which the system is aware. They may be used as synonyms for predictions or expectations. Implicit anticipations, by contrast, work below the threshold of consciousness. They may be active within the system without the system itself being aware of them. Implicit anticipations are properties of the system, intrinsic to its functioning. As far as explicit anticipation is concerned, the reflexive side of explicit anticipation becomes visible as the difference between looking into the future and taking account of the consequences of that looking, i.e., as the impact of an anticipation on current behavior. The types or aspects of behavior that can be modified through anticipation are exemplifications of normative behavior. If the system evaluates its own evolution as positive (according to its own criteria), it will maintain its behavioral patterns; conversely, if the system evaluates its own evolution as negative, it may seek to change its behavioral patterns in order to prevent the occurrence of the anticipated negative results. A major question is whether explicit anticipations depend – or to what extent they may depend – on implicit ones. Finding the correct answer to this question is far from being a trivial undertaking. The apparently obvious answer that explicit anticipation depends – at least to some extent – on implicit anticipation may beg the question. For it may well turn out that the two forms of anticipation are based either on entirely different enabling conditions, or on different subsystems. This last case makes sense as soon as one envisages a system composed of different subsystems.

Anticipation exhibits a variety of temporal patterns. Perceptual microanticipations may unfold in microseconds, while forms of social anticipation may range from seconds to years and decades.

Anticipation has been a major evolutionary discovery. From an evolutionary point of view, explicit anticipation is an advantage because it enables more rapid goal-directed processing. The other side of the coin, however, is that focused goal-oriented behavior usually gives rise to inattentional blindness, i.e., the incapacity to perceive things that are in plain sight. Patterns constrain attention, govern the boundary of relevance, and they direct attention to preestablished foci. The more efficient the patterns, the more likely is the outcome of an over-restricted focus of attention. The more efficient the behavioral patterns are, the more rigid they become.

Anticipation may be partially independent from memory. Anticipatory capacities may depend on the internal organization of the system and do not necessarily depend on previous memories. This amounts to saying that anticipation lies deeper than memory in the functional structure of organisms. It apparently also applies to both psychological and social systems. This is an important contention which requires firmer supporting evidence.

Different types of anticipation may be at work contemporaneously. None of the best-known theories have yet explicitly addressed the problem that systemic behavior may be the result of processes unfolding at different levels of reality, including the biological level (perception, brain processes), the psychological level (cognitive processes), and the social level (social interactions). For complex systems such as ourselves, biological, psychological, and social types of anticipation may work in parallel. They have their own temporal patterns, and may be distinguished by other properties as well. Moreover, when different types of anticipation are simultaneously active, they may work harmoniously together or they may interfere with each other.

Cross-References

► Anticipation and Learning
► Anticipatory Learning
► Anticipatory Learning Mechanisms
► Anticipatory Schema(s)

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Marital and Family Systems Model

► Application of Family Therapy on Complex Social Issues

Marking Criteria

► Learning Criteria, Learning Outcomes, and Assessment Criteria

Marking Grid

► Learning Criteria, Learning Outcomes, and Assessment Criteria

Marking Matrix

► Learning Criteria, Learning Outcomes, and Assessment Criteria

Marking Rubric

► Learning Criteria, Learning Outcomes, and Assessment Criteria

Marking Schemes

► Learning Criteria, Learning Outcomes, and Assessment Criteria

Marking Standards

► Learning Criteria, Learning Outcomes, and Assessment Criteria

Marx, Karl (1818–1883)

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Life Dates

Born in Trier on the river Moselle, Karl Marx was educated at the Universities of Bonn, Berlin, and Jena. Both his parents were converted Jews. His stinging journalistic critiques of social conditions and of the Prussian government led to exile from Germany in 1843. After short stays in Paris and Brussels, he decamped to London where he remained. He was instrumental in the birth of European socialism, while also a tireless reader, analyst and writer, mostly at the British Museum which then housed the British Library. He fathered eight children, living by meagre earnings as a journalist and with the support of the industrialist Friedrich Engels (1820–1895) who also was his frequent collaborator. No more than a dozen people attended his funeral, but since then his tombstone at London's Highgate Cemetery has attracted a constant pilgrimage, including V. I. Lenin. Marx's single most famous work is *The Communist Manifesto* (1848), but there are many others, including the multi-volume *Capital* (1867). His collected works, including the journalism, run to 25 volumes. Some titles are very substantial. By any measure he is one of the most influential thinkers ever.

Theoretical Background

In politics, both communism and socialism trace back to Marx. He has also had an even greater influence among intellectuals. In the 1960s Marxism entered economics, political science, sociology, anthropology, and other social and human sciences. For a generation of intellectuals it was *de rigueur* to denounce liberal democracy in the name of Marx. His legacy was claimed and disputed by all manner of self-appointed Marxists throughout the Western world, while elsewhere in the Communist East his texts remained a gospel of stone and barbed wire. With the collapse of the Soviet Union and its European dependencies, Marxism in the Western academy has become less strident, but it remains in hibernation. While Marx never discussed learning or education in a sustained way, he has had a tremendous impact on educators and researchers throughout the world. In the Communist regimes that impact was material and pervading, though hardly the liberation of the human spirit that Marx desired.

Marx saw labor as a positive experience in enhancing human life. Industrialism as he saw it was destroying that positive element. The emphasis on the spiritual value of labor is clearest in his early works but it continued, by implication, in his later, more technical studies. Properly organized labor was a medium of human expression, and not just a necessary evil to reproduce life. It is through labor that an artisan learns to express ideas in the material of the world. This process is the objectification of the personality of the worker. That is, the process creates a product (the object) that embodies, to some degree, the distinct personality of the artisan. This sense of unique craftsmanship remains well understood and highly valued, as distinct from mass-produced items that are equally functional, less expensive, and often more durable. It is in his lifelong criticisms of child-labor that Marx explicitly refers to the need to combine productive labor with education. Such sentiments can be found in the *Economic and philosophic manuscripts* (also known as the *Paris manuscripts*) (1844), *Communist manifesto* (1848), *Capital* (1867), and the *Critique of the Gotha Program* (1875). The value of education was that it enabled workers to express themselves. If it also made them more productive, as is frequently argued today, for Marx that would be an unintended by-product. He sought to identify the alienating aspects of labor that subtracted the worker's personality from production. Meaningful work reveals and enhances the abilities and experiences of workers. Mass production with its assembly lines of robotic workers was anathema to Marx. He was ahead of his time in several ways. First, he foresaw the logic of mass production even before it was fully developed in the assembly line that reduced workers to cogs in a giant machine. Second, he also prefigured the recognition in the latter twentieth century that creative labor enhances high quality production. The most visible example is the change in automobile production from a production line to a manufacturing team (Nagel et al. 1991, p. 32).

Contribution(s) to the Field of Learning

The foundation of Marx's thought was materialism. He supposed that the material world determined thought, and for this reason broke with Georg Hegel's Idealism. In Marx's phrase, "life determines consciousness" (*German Ideology* 1846, p. 155). Our experience determines our thoughts. He elaborated a theoretical vocabulary to express and extend this insight. Ideas, emotions, and thoughts, these are all derived from superstructure. The base consists of economic relations. From this point, Marx developed a class theory of social order and social relations. Knowledge is not neutral, nor are the artifacts that science examines natural, but rather both are products of class relations based on economic ownership. The normal activities of teaching and research perpetuate class relations. We make reality in our own image and it in turn reproduces us in that image. A later Italian Marxist, Antonio Gramsci (1891–1937), developed this theme in his *Prison Notebooks* (1930–1932) as hegemony, a concept that is now widely used throughout the social sciences and humanities. Western acolytes of Marx have argued, among other things, that liberalism was repressive and that electoral democracy was a sham. An example is Herbert Marcuse's *Repressive Tolerance* (1965), which was required reading for a generation. Enthusiasts for Marxism in the 1970s claimed that Enver Hoxha's Albania or Mao's Cultural Revolution represented greater human achievements than the hoax of liberal democracy. Later Pol Pot and other sovereign murderers had apologists among their number.

Though leaders of industry in the twenty-first century do not cite Marx, they do echo him when they call for learning organizations and stress the unique value of human capital in workers. Corporations likewise echo Marx when they stress the unique capacities that their workers apply to the manufacturing. When Volvo and Acura advertise the people who build their cars, because both have changed the method of manufacture to make it more effective and that has made it more satisfying to workers, they are downstream from Marx.

What remains of Marxism today? The emphasis on materialism and social forces, as distinct from ideas and individuals, remain bedrocks in all the social and human sciences. There also remains a recognition of social structure and the importance of the economic base of social relations. Similarly, the neutrality of knowledge – in teaching and in research – remains contested. However, much of what was distinctly Marxist has been integrated into the social and human sciences and has changed as a result. The union of Marx's analysis of society with a political program has been divorced in both the West and the East. Today *The Communist Manifesto* comes installed on electronic books sold by major multinational corporations like Sanyo.

Cross-References

▶ Social Construction of Learning

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Mastering

▶ Internalization

Mastery and Performance Goals

▶ Age-Related Differences in Achievement Goal Differentiation

Mastery Goal

A motivational system whereby individuals are oriented toward developing new skills, trying to understand their work, improving their level of competence, or achieving a sense of mastery.

Mastery Learning

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Synonyms

Learning for mastery

Definition

Mastery learning is a philosophy and set of instructional strategies designed to help teachers better individualize teaching and learning in group-based classrooms. In using mastery learning, teachers first organize the concepts and skills they want students to acquire into learning units that typically involve about a week or two of instructional time. Following initial instruction on the unit, teachers administer a brief formative assessment based on the unit's learning goals to offer students "feedback," on their learning progress. Paired with each formative assessment are specific "corrective" activities, designed to guide students in correcting any identified learning difficulties. With the teacher's guidance, students complete their corrective activities in a class period or two and then take a second, parallel formative assessment. This second assessment verifies whether or not the correctives were successful in helping students overcome their individual learning difficulties and offers students a second chance at success. Students who perform well on the first formative assessment and demonstrate that they have mastered the unit concepts and skills are engaged in special "enrichment" or "extension" activities to broaden their learning experiences. Through this process of regular classroom formative assessments, combined with the systematic correction of individual learning difficulties, mastery learning theorizes that all students can be provided with a more appropriate quality of instruction than is possible under more traditional approaches to teaching.

Theoretical Background

Although the basic tenets of mastery learning can be traced to such early educators as Comenius, Pestalozzi, and Herbart, most modern applications stem from the writings of Benjamin S. Bloom of the University of

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Chicago. In the 1960s, Bloom began a series of investigations on the variation that existed in student learning outcomes. He recognized that while students vary widely in their learning rates, virtually all learn well when provided with the necessary time and appropriate learning conditions. If teachers could provide the time and more appropriate conditions, Bloom reasoned that nearly all students could reach a high level of learning.

To determine how this might be practically achieved, Bloom first considered how teaching and learning take place in typical group-based classrooms. He observed that most teachers begin by dividing the concepts and skills that they want students to learn into smaller learning units. Following instruction on the unit, teachers administer some form of assessment to determine how well students have learned those concepts and skills. Based on the assessment results, students are sorted, ranked, and assigned grades. The assessment signifies to students the end of the unit and the end of the time they need to spend working on the unit material. When teaching and learning proceed in this manner, Bloom found that only a small number of students learn well and truly master the intended learning goals.

Seeking a strategy that would produce better results, Bloom drew upon two sources of information. He first considered the ideal teaching and learning situation in which an excellent tutor is paired with each student. He was particularly influenced by the work of early pioneers in individualized instruction, especially Washburne's Winnetka Plan and Morrison's experiments at the University of Chicago Laboratory School. In examining this evidence, Bloom tried to determine what crucial elements in one-to-one tutoring and individualized instruction could be transferred to group-based classroom settings. Second, Bloom looked at studies of the learning strategies of academically successful students and tried to identify the activities of high-achieving students in group-based classrooms that distinguish them from their less successful classmates.

Bloom saw value in organizing the concepts and skills to be learned into units and assessing students' learning at the end of each unit as useful instructional techniques. But the classroom assessments most teachers used seemed to do little more than show for whom their initial instruction was and was not appropriate. Bloom believed a far better approach would be for teachers to use their classroom assessments as learning tools, and then to follow those assessments with a feedback and corrective procedure. In other words, instead of using assessments only as evaluation devices that mark the end of each unit, Bloom recommended using them as part of the instructional process to identify individual learning difficulties (feedback) and to prescribe remediation procedures (correctives).

This is precisely what takes place when an excellent tutor works with an individual student. If the student makes a mistake, the tutor first points out the error (feedback) and then follows up with further explanation and clarification (correctives) to ensure the student's understanding. Similarly, academically successful students typically follow up the mistakes they make on quizzes and assessments. They ask the teacher about the items they missed, look up the answer in the textbook or other resources, or rework the problem or task so that they do not repeat those errors.

With this in mind, Bloom outlined an instructional strategy to make use of this feedback and corrective procedure, labeling it "Learning for Mastery" (Bloom 1968), and later shortening it to simply "Mastery Learning" (Bloom 1971). With this strategy, teachers first organize the concepts and skills they want students to learn into learning units that typically involve about a week or two of instructional time. Following initial instruction on the unit, teachers administer a brief quiz or assessment based on the unit's learning goals. Instead of signifying the end of the unit, however, this assessment's purpose is to give students information, or "feedback," on their learning. To emphasize this new purpose Bloom suggested calling it a *formative assessment*, meaning "to inform or provide information." A formative assessment identifies for students precisely what they have learned well to that point, and what they need to learn better (Bloom et al. 1971).

Paired with each formative assessment are specific "corrective" activities for students to use in correcting their learning difficulties. Most teachers match these "correctives" to each item or set of prompts within the assessment so that students need to work on only those concepts or skills not yet mastered. In other words, the correctives are "individualized." They may point out other sources of information on a particular concept, identify alternative learning resources, or simply suggest sources of additional practice, such as study guides, computer exercises, independent or guided practice activities, or collaborative group activities.

With the feedback and corrective information gained from the formative assessment, each student has a detailed prescription of what more needs to be done to master the concepts or skills from the unit. This "just-in-time" correction prevents minor learning difficulties from accumulating and becoming major learning problems. It also gives teachers a practical means to vary and differentiate their instruction in order to better meet students' individual learning needs. As a result, many more students learn well, master the important learning goals in each unit, and gain the necessary prerequisites for success in subsequent units.

When students complete their corrective activities after a class period or two, Bloom recommended they take a second "parallel" formative assessment that covers the same concepts and skills as the first, but is composed of slightly different problems or questions. This second assessment verifies whether or not the correctives were successful in helping students overcome their individual learning difficulties. It also offers students a second chance at success and, hence, has powerful motivational value.

Some students, of course, will perform well on the first assessment, demonstrating that they have mastered the unit concepts and skills. The teacher's initial instruction was highly appropriate for these students and they have no need of corrective work. To ensure their continued learning progress, Bloom recommended that teachers provide these students with special "enrichment" or "extension" activities to broaden their learning experiences. Enrichment activities typically are self-selected by students and might involve special projects or reports, academic games, or a variety of complex, problem-solving tasks.

Bloom believed that through this process of formative classroom assessment, combined with the systematic correction of individual learning difficulties, all students could be provided with a more appropriate quality of instruction than is possible under more traditional approaches to teaching. As a result, nearly all might be expected to learn well and truly master the unit concepts or learning goals (Bloom 1976).

Important Scientific Research and Open Questions

Teachers who implement mastery learning generally find that it requires only modest changes in their instructional procedures. Excellent teachers use many aspects of mastery learning in their classes already, and others discover that the process blends well with their current teaching strategies. Despite the modest nature of these changes, however, extensive research evidence shows that the use of mastery learning can have exceptionally positive effects on student learning (Guskey and Pigott 1988; Postlethwaite and Haggarty 1998; Walberg 1990), and also shows that the careful and systematic application of these elements can lead to significant improvements in a wide variety of student learning outcomes.

Long-term investigations have yielded similarly impressive results. A study by Whiting et al. (1995), for example, representing 18 years of data gathered from over 7,000 high school students showed mastery learning to have remarkably positive influence on students' test scores and grade point averages as well as their attitudes toward school and learning. Another field experiment conducted in elementary and middle school classrooms showed that the implementation of mastery learning led to significantly positive increases in students' academic achievement and their self-confidence (Anderson et al. 1992). Likewise, a comprehensive, meta-analysis review of the research on mastery learning by Kulik et al. (1990) concluded, "Few educational treatments of any sort (are as) consistently associated with achievement effects as large as those produced by mastery learning. . . . In evaluation after evaluation, mastery programs have produced impressive gains" (p. 292).

Researchers today generally recognize the value of the essential elements of mastery learning and their importance in effective teaching at any level of education. As a result, fewer studies are being conducted on the mastery learning process, per se. Instead, researchers are looking for ways to enhance results further, adding additional elements to the mastery learning process that positively contribute to student learning in hopes of attaining even more impressive gains. Recent work on the integration of mastery learning with other innovative strategies appears especially promising (Guskey 1997).

In his later writing Bloom, too, described exciting work on other ideas designed to attain results even more positive than those typically achieved with mastery learning (Bloom 1984). These ideas stemmed from the work of Bloom and his students comparing student learning under three different instructional conditions: conventional instruction, mastery learning, and individual tutoring. The differences in students' achievement under these three conditions were striking. Using the standard deviation (sigma) of the control (conventional) class as the measure of difference, Bloom discovered that the average student under tutoring was about two standard deviations above the average of the control class. In other words, the average tutored student was above 98% of the students in the control class. The average student under mastery learning was about one standard deviation above the average of the control class, that is, the average mastery learning student was above 84% of the students in the control class.

Bloom referred to this as the "2 Sigma Problem": Can researchers and teachers devise teaching-learning conditions that will enable the majority of students under group instruction to attain levels of achievement that can at present be reached only under tutoring conditions? Bloom believed that attaining this high level of achievement would probably require more than just improvements in the quality of group instruction. Researchers and teachers might also need to find ways of improving students' learning processes, the curriculum and instructional materials, the home environmental support of students' school learning, and providing a focus on higher level thinking skills. Nevertheless, Bloom remained convinced that careful attention to the elements of mastery learning would allow educators at all levels to make great strides in their efforts to reduce the variation in student achievement, close achievement gaps, and help all children to learn excellently.

Cross-References

- ► Abilities to Learn: Cognitive Abilities
- ► Adaptive Instruction System(s) and Learning
- ► Bloom's Model of School Learning
- ► Competency-Based Learning
- ► Student-Centered Learning

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Mastery-Challenge Goals

► Goal Theory/Goal Setting

Matched Pair Tandem Designs

► Field Experiments in Learning Research

Matching

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Synonyms

Discriminative law of effect; Generalized matching law; Law of simple action; Matching law; Quantitative law of effect

Definition

Generically, matching is a set of quantitative theories concerned with choosing between alternatives, where choosing is defined as allocating behavior (responses or time spent responding). The original theory, proposed by Herrnstein (1970), was strict-matching theory. This theory suggested that animals and humans allocate behavior or time to available alternatives simply in proportion to the payoff (reinforcers) that they obtain from the alternatives. With some additional assumptions, Herrnstein proposed the Law of Simple Action (the quantitative law of effect, or Herrnstein's hyperbola) to describe the rate of responding produced by varying reinforcer frequencies for a single response. However, strict-matching theory failed to describe all choice data accurately, and was replaced by generalized matching by Baum (1974) and Staddon (1968). Generalized matching introduced the notion of sensitivity to reinforcement and bias, which accounted for common deviations from strict matching, and provided enhanced accuracy of the description of choice. The generalized matching relation has been extended to take into account many other aspects of reinforcers and responses, and this generalization is called the concatenated generalized matching relation.

A further set of matching theories, originally based on generalized matching, generically called the discriminative law of effect, attempted to extend the domain of applicability of matching theory to stimulus or situational control of choice. Recent versions of this approach (Davison and Nevin 1999) assume that behavior allocation results from animals discriminating both the contingencies of reinforcement and the stimulus contingencies that signal these response-reinforcer contingencies. Thus, animals and humans learn to discriminate between differing situations or environments that signal different choice options and reinforcers for different responses.

A number of theories of matching have been proposed, notably molecular maximization and molar maximization. Molecular maximization suggests that choice arises from animals emitting the response that has the highest momentary probability of reinforcement; while molar maximization says that it arises from animals choose so as to maximize the overall rate of obtaining reinforcers.

Theoretical Background

As Herrnstein (1970) pointed out, to understand choice and the allocation of behavior between activities is, *ipso facto*, to understand all behavior – because, he argued, all behavior is choice.

In the analysis of steady-state choice in experimental settings, the term *matching* refers to the empirical finding in the 1960s that relative choice between pairs of outcomes that are unpredictable in time equals the relative frequency of food (or other reinforcer) deliveries. This finding was formalized as the equation

$$\frac{B_1}{(B_1 + B_2)} = \frac{R_1}{(R_1 + R_2)}$$

which is now known as the *strict matching relation. B* and *R* are numbers of responses (or time spent responding) and obtained numbers of food or other reinforcers, respectively, and the subscripts denote the choice alternatives. Initial empirical research showed that the right-hand side of the equation could also be relative magnitude or relative delay of reinforcers, but see below. This equation, coupled with some further assumptions, was the basis of the quantitative law of effect proposed by Herrnstein in the early 1970s. However, further empirical research and data reanalyzes showed frequent and systematic deviations from strict matching, and the law was subsequently modified to the generalized matching law.

The equation of the generalized matching law (Baum 1974; Staddon 1968) is as follows:

$$\log\frac{B_1}{B_2} = a\log\frac{R_1}{R_2} + \log c$$

The deviations from strict matching are accounted for by the two additional parameters: log *c* is called bias, and describes a constant proportional preference for one alternative over the other that is independent of the variable (here, reinforcer frequency) that is changed; the parameter *a* is called sensitivity to reinforcement, and describes the finding that choice may change to a greater or lesser extent when reinforcer frequencies are changed. Generally, *a* has been found to be less than 1 (called under-matching), though it can be reliably greater than 1 when choice is punished or when substantial work is required to move or travel from one alternative to the other. The generalized matching relation fits choice data very nicely, with proportions of variance accounted for in both animal and human data most often exceeding 95%.

The generalized matching relation has been concatenated for a number of different variables that affect choice (the concatenated generalized matching law):

$$\log\frac{B_1}{B_2} = a_r \log\frac{R_1}{R_2} + a_m \log\frac{M_1}{M_2} + a_d \log\frac{D_2}{D_1} + a_f \log\frac{F_2}{F_1} + \log c$$

where M is reinforcer magnitude, D is reinforcer delay, and F is response force, and the a parameters are the respective sensitivity values. Reinforcer quality (Q) has also been brought into this equation, and used in a lot of agricultural research, but it can only be measured as a constant when some other variable (such as R) is systematically varied and qualities are kept constant. Magnitude sensitivity has often been reported as about 0.5 (but there are some reports of 1.0), and force sensitivity appears to be about 1.0. This relation again fits data very well indeed, and is clearly an excellent description.

Important Scientific Research and Open Questions

The generalized matching relation was initially shown to work well for choice between more than 2 (and up to 5) alternatives when applied to each pair of choices. The implications of this finding is that choice is consonant with the constant-ratio rule (also known as the principle of indifference from irrelevant alternatives), a choice axiom suggested by mathematical psychologists. This means that choice, or behavior allocation, between two alternatives is unaffected by the values of all other alternatives. However, some recent detailed analyzes of four-alternative choice has shown this is not generally true, and have shown reliable curvilinear deviations from the straight lines on double-logarithmic coordinates that are predicted by generalized matching.

Indeed, the implication of generalized matching, that choice is affected only by the ratio of outcomes has generally been found wanting. It has been shown that sensitivity to constant reinforcer ratios (a_r) is affected by the overall rate of reinforcers; that sensitivity to constant reinforcer magnitudes (a_m) is affected by the absolute size of the reinforcers; and that sensitivity to constant reinforcer delays (a_d) is affected by the absolute size of the delays. It has also been shown that sensitivity to reinforcer magnitude is affected by overall reinforcer rate. Sensitivity to reinforcer ratios is affected by the degree to which animals can discriminate the alternatives. Research on extreme choice has shown deviations from generalized matching at the extremes and even constant, but clearly nonexclusive, preference when one alternative provides no reinforcers, and that choice in this situation is independent of the overall rate of reinforcers on the alternative that does pay off. All of these results are incompatible with the generalized matching relation.

A further problem for generalized matching concerns the sensitivity parameters. These cannot be organismic (i.e., due to the way in which individual animals work), because their values can be changed by environmental manipulation. Thus, they are environmentally caused, but the generalized matching relation does not attempt to account for this environmental causation. This seems especially pertinent when research on choice is done with humans, rather than with animals. Humans do show a much wider range of sensitivity values than do animals in constrained experimental environments, and this range may well arise from details of the responses and reinforcers used, and from the decreased environmental control that occurs when working with humans.

However, despite all these problems, the generalized matching relation works well and is very accurate. In applying it to human choice in applied situations, all that is required is that sensitivity to the reinforcer used in the situation is measured, and that choice is not too extreme. Under these conditions, it is possible to quantify quite precisely the amount of intervention required to change behavior allocation to any desired level. Thus, the generalized matching relation is useful; but it is not theoretically correct. It does not have the status of a law, despite it often being called the generalized matching "law."

In the late 1970s, the generalized matching relation was extended to provide a quantitative model of the way in which discriminative stimulus conditions modulate the control of choice by reinforcers. This approach was developed quantitatively to describe choice in conditional-discrimination and signal-detection procedures and is sometimes called the discriminative law of effect. The original model provided a measure, log *d*, of how well an animal discriminated between two stimuli or situations that signaled different contingencies of reinforcement – independently of the effects of the reinforcers. This model, especially its derived parameter log *d*, has been extensively used. However, it was superseded in the early 1990s (see Davison and Nevin 1999) by a further discriminative law of effect that had the avowed intention of describing both conditional–stimulus-control and reinforcer control in the same, stimulus-control, terms: It had two parameters, one measuring the degree to which an animal could discriminate between response-reinforcer relations (which behavior was related to which reinforcer), and the other measuring the degree to which an animal could discriminate stimulus-response relations (which responses could be reinforced in which situation). When the model is simplified to a model of simple choice, it accurately describes the extreme choice results mentioned above, and some, but not all, of the other difficulties of the generalized matching relation. The major benefit of this model is that it does directly imply the environmental operations needed to change the two parameters, and some research strongly supportive of this approach to conditional discrimination has been reported. The model has also been used as the basis of some recent theoretical developments, applying this discriminative law of effect to many outstanding theoretical and empirical problems in a number of areas. However, it does have a major drawback; it has not been concatenated to work with variables that affect choice other than reinforcer frequency. A further drawback that makes it harder to use is that it is a nonlinear model, so more data have to be collected to fit the model compared to the generalized matching relation.

There have been many, varied, attempts to derive matching, usually strict matching, from considerations of processes at lower levels – for example, from assumptions that animals emit the response that momentarily has the higher probability of reinforcement (molecular maximizing), or assumptions that animals change their choices to get overall the highest rate of reinforcers from a situation (molar maximizing). While many of these have been effective for the data sets for which they were developed, none currently seems to have sufficient generality. A different approach has recently been taken which eschews low-level mechanistic effects, and sees matching resulting from the relation between extended activities (responding) and the reinforcer rates in the presence of these activities. Indeed, the study of dynamic systems does suggest that relations can occur at a level of analysis that is unpredictable from lower levels of analysis. A further recent approach has been to see behavior allocation as resulting from an evolutionary process in which responses are selected by their consequences. While simulations based on this evolutionary algorithm produce behavior very similar to generalized matching, the problem of *post hoc propter hoc* remains until this approach can make some novel predictions that are empirically found to be correct.

Recently, research on choice and matching has moved from trying to understand steady-state choice to trying to understand transitions in choice – returning to the original question of learning. This research has found some remarkable, and unexpected, regularities at very fine levels of analysis such as short-term transient pulses in preference following both reinforcers and purported conditional reinforcers. However, the direction of these pulses is not always toward the alternative that provided the last reinforcer – rather, the direction depends on what these reinforcers (or conditional reinforcers) signal about the likely location and time of the next reinforcer. What reinforcers seem to be doing is acting as signals, rather than increasing the probability of responses that they follow as described by the Law of Effect. This has led some researchers to question whether theorists might have been wrong about what reinforcers do for over 100 years (since the Law of Effect was first suggested by Thorndike). This research has also shown that learning, or adaptation to new reinforcement conditions, is considerably faster when environments change frequently than when they change infrequently. This finding may have some very important implications for behavior change in applied practice.

Finally, it could be argued (though not by this contributor) that research on quantitative theories of choice and behavior allocation has become too concerned with gaining very small increments in understanding, too divorced from the practical necessities of learning, and behavior change and behavior maintenance. The basic matching relations do work very well, and for practical purposes they have been used very effectively and may suffice for most practical problems. But, there are a number of reasons why continued research in the area is important. The first is that a better theory is needed to understand the full range of choice – extreme choice is, of course, a common presentation in applied areas, and it still is in need of an effective theory. Second, the better the quantitative description of choice, the easier it will be to link effectively with the neuroscience of learning and behavior. Last, but by no means least, forgetting all links and applications, there is the unadulterated desire to advance the fundamental understanding of behavior.

Cross-References

- ► Animal Learning and Intelligence
- ► Associative Learning
- ► Behaviorism and Behaviorist Learning Theories
- ► Behavior Systems and Learning
- ► Evolution of Learning
- ► Instrumental Learning
- ► Law of Effect
- ► Mathematical Models/Theories of Learning
- ► Operant Behavior
- ► Psychology of Learning
- ► Reinforcement Learning
- ► Reinforcement Learning in Animals
- ► Schedules of Reinforcement
- ► Signal-Detection Models
- ► Skinner, B.F. (1904–1990)
- ► Matching to Sample Experimental Paradigm

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Matching Law

► Matching

Matching to Sample Experimental Paradigm

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Synonyms

Conditional discrimination; Matching; Oddity; Visual search

Definition

In a typical matching to sample (MTS) procedure, a participant is presented with a single stimulus called the sample (e.g., blue circle) and then with two choice stimuli called the comparisons (e.g., blue circle, orange circle). The participant is rewarded for selecting the comparison that matches the sample. If the sample is present at the time of choice the task is called simultaneous MTS otherwise it is called delayed MTS. The MTS procedure has remained at the forefront of psychological research because it can be solved by different strategies, thereby helping to reveal the cognitive flexibility of human and nonhuman species.

Theoretical Background

The MTS procedure can be learned by both item-specific and relational strategies (Katz et al. 2007). Item-specific strategies involve rote memorization and either configural or if-then rule learning. Configural learning refers to learning the entirety of each display as a whole stimulus (i.e., a pattern or gestalt) and learning to respond to a comparison choice based on this pattern. For example, participants may learn: green-sample, red-left comparison, green-right comparison, then choose green-right comparison, as one rule, and learn green-sample, green-left comparison, red-right comparison, then choose green-left comparison, as another rule. If-then rule learning involves learning individual stimulus-response pairs to the sample and each correct comparison stimuli. For example, participants may learn: if green-sample, then choose green comparison. Participants learn separate rules for each possible configuration or if-then rule in the training set of stimuli. These forms of item-specific learning are bound to the training set of stimuli (i.e., the domain), sometimes including their specific spatial relationships. In contrast, relational strategies are not confined to the training set. ► Relational strategies require participants to identify a relationship between the sample comparison stimuli (e.g., identity, oddity) within the training stimulus domain.

Determining which strategy participants utilize is examined via a transfer test. After participants reach a performance criterion (e.g., number of training trials, percent correct), transfer testing typically occurs in which novel stimuli are mixed with training stimuli within the same session. If transfer performance (i.e., accuracy on transfer trials) is not significantly different from chance, the participants are responding based on item-specific learning and such learning is restricted to some aspect of the training stimulus domain. If transfer performance is equivalent to baseline performance, then abstract-concept learning has occurred. In some cases, relational learning can occur in the absence of ► abstract-concept learning (Wright and Katz 2009). If transfer performance is between chance and baseline performance, it is difficult to know what strategy is controlling behavior. Parametric manipulation of critical variables (e.g., training set size) may show the relative control of behavior by these competing strategies.

The issue of item-specific and relational learning is central to all learning and that is why MTS has been utilized to address issues in cognitive development, cognition, and comparative cognition research. Specifically, MTS is used to explore aspects of mathematical operations, conservation tasks, language acquisition, and other abstract concepts (e.g., Siegler and Alibali 2004). Because MTS does not require a verbal response it can be tested in a variety of species. Hence, the MTS experimental paradigm can provide important indications about which species possess these abilities and how mechanisms of learning are influenced.

Important Scientific Research and Open Questions

When developing novel transfer tests, the extent of the novelty must be dealt with immediately. Strictly speaking, so long as the transfer stimuli are not perceptually identical to the training stimuli, relational learning can be assessed. What shall we say when participants learn MTS with picture stimuli, transfer to novel picture stimuli, but fail to transfer to auditory stimuli? In this case, the participant has clearly learned an abstract rule (the rule is not bound to item-specific features), but the domain is restricted. Studies of expertise in humans are replete with examples of experts in a given domain (e.g., extreme feats of memory for chess pieces) not showing increased ability across domains (e.g., an increased general memory). The way these relational concepts change across development is also a key issue (Doumas et al. 2008). The MTS paradigm presents an efficient method to test the conditions under which rules learned under a given domain may or may not transfer to other domains.

The MTS procedure is often used to teach language skills to individuals with developmental disabilities (e.g., Autism Spectrum Disorder). Three building blocks of language can be assessed within the MTS paradigm: reflexivity, symmetry, and transitivity. First, we slightly modify the paradigm so that instead of matching samples to identical comparison objects, samples are matched to comparisons with equivalent meaning. The sample may be a written word and the comparisons pictures, one of which depicts the word. The empirical question is whether after repeated word-picture trials individuals will be able to solve trials based on emergent relations. The test for reflexivity is a test of identity: matching written word to the identical written word. To test for symmetry, the stimulus types for sample and comparison are reversed. If trained on word-picture trials, can individuals solve novel picture-word trials? The final component, transitivity, is demonstrated by combining relations learned on separate trials. Having learned to match words (sample) with pictures (comparison) and pictures (sample) with audible words (comparison), will individuals match words (sample) with audible words (comparison)? Symbolically, after learning A::B, and B::C, transitivity implies the relation A::C. Raising the issue of whether nonhuman animals may be able to use something akin to human language, researchers have demonstrated the emergence of these three properties in nonhuman primates, marine mammals, but not yet with other nonhuman species.

Although the transfer test method can uncover the strategy being used to solve the matching to sample task, the underlying representation supporting the discrimination is an area of active research. A primary concern is whether individuals solve the task based on perceptual similarity of the sample and comparisons, or by using a memory-based strategy. The perceptual strategy implies that individuals actively compare the sample to each comparison, responding to the object that is the same as the sample. The memory-based hypothesis suggests that individuals form a mental code (i.e., a memory) of the sample object, and this is compared to the two comparison objects. If participants are actively encoding the sample object, then inserting a small delay between the sample and comparison presentations should not completely disrupt performance. In fact, as the delay increases, matching accuracy should tend toward chance accuracy. When participants initially learn an MTS task without a delay, they typically do poorly when delays are introduced, but steadily improve with continued training. A wide range of species have been tested in this delayed MTS procedure, conclusively demonstrating impressive memory ability in an array of vertebrate species (e.g., humans, nonhuman primates, rodents, aves, dolphins, elephants) and even invertebrates (e.g., honeybees; Shettleworth 2010). An obvious implication from these results is to characterize a species' memory ability by assessing its MTS performance at expanded delays.

A hot issue is whether participants are aware of when they remember/forget the sample object. Often called metamemory, or more broadly, ► metacognition, the basic procedure consists of allowing participants to "opt out" of the memory test. The reward for opting out is less than that for getting the memory test correct, ensuring that taking the memory test should be preferred when memory for the sample is strong. Testing humans in such a setup can confirm that we are capable of recognizing that we have forgotten previously presented information, but has much greater implications for our understanding of nonhuman cognition. The results suggest that nonhuman primates and perhaps rats can make decisions based on metamemory, although not all criticisms have been summarily satisfied (cf. Crystal and Foote 2009). The way that nonhumans represent information and the extent to which they are aware of their cognition remains an active area of research and the MTS paradigm may be the primary tool with which to assess it.

Cross-References

► Abstract Concept Learning in Animals
► Associative Learning of Pictures and Words
► Concept Learning
► Metacognition and Learning
► Transfer of Learning

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Material Appropriate Processing

Material appropriate processing (MAP) is the concept that recall in enhanced when encoding strategies encourage processing that is not redundant with the type of processing already invited by the stimuli.

Material Specificity

A neurocognitive model that, in its strongest form, postulates the existence of two discrete memory systems in the left and right temporal lobes. The left temporal system is a necessary substrate for processing learning tasks consisting of verbal material, while the right temporal system is specialized for tasks consisting of nonverbal material.

Materials-Based Learning

► Resource-Based Learning

Math Learning Disabilities

► Dyscalculia in Young Children: Cognitive and Neurological Bases

Mathematical Learning

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Synonyms

Mathematics learning

Definition

Mathematics learning can be broadly defined as the acquisition of new knowledge, skills, and affects that are related to quantity, space, and structure. The ability to learn mathematics is possessed by humans and to some extent also by some animals and machines. As far as humans are concerned, its acquisition is considered to be the result of the complex interplay of various elements: innate, though plastic, neurobiological structures, as well as perceptual and action schemes that allow basic quantitative and spatial activities (such as subitizing and quantity comparison); preschool and out-of-school activities and experiences related to number, space, and patterns; and intentional, explicit, and systematic mathematics learning in school.

When people refer to mathematics (sometimes shortened to *maths* or *math*), they mostly refer to formal academic or professional mathematics – i.e., the scholarly study of quantity, space, and structure, by seeking out patterns, formulating new conjectures, and establishing truth by rigorous deduction from appropriately chosen axioms and definitions, or the simplified version of it they learnt at school. But mathematics also involves the more informal kinds of human practices related to number, space, and patterns that are present in human activities like counting, locating, measuring, designing, playing, and explaining.

Although there are important differences between distinct subdomains of mathematics (such as arithmetic, algebra, geometry, probability, and statistics), it is generally unquestioned that mathematics retains integrity as an intellectual domain. One major feature of mathematics that makes it significantly different from other intellectual or scientific domains is its dual nature: mathematics as a descriptor of a perceived reality and as an autonomous abstract construction. This duality is acknowledged in the distinction between applied mathematics (the branch of mathematics concerned with application of mathematical knowledge to other fields such as natural science, engineering, medicine, and social sciences) and pure mathematics (mathematics for its own sake, without having any application in mind). These different aspects of mathematics, the practical and theoretical, have earned the subject a place at the center of education throughout history.

Theoretical Background

Mathematics learning has been studied by a wide variety of scientific disciplines, such as neuropsychology, experimental, developmental, and educational psychology, instructional science (or pedagogy), ethnography, sociology, and anthropology. During the last decades, research in mathematics learning and teaching has emerged as a field of scientific study in its own right. After a long struggle for its identity, mathematics learning has become a full-fledged interdisciplinary field of research, the key aim of which is to better understand the processes underlying the acquisition and development of mathematical knowledge/skills/affects, and to use this understanding for the design of valuable tools and powerful environments for teaching/learning mathematics.

The study and analysis of the nature of mathematical cognition and how it is learnt can be categorized in different theoretical traditions. In general, there are three major traditions that frame the nature of knowing and learning in mathematics, namely, in contrasting and complementary ways: the behaviorist/empiricist, the cognitive/rationalist, and the situative/pragmatist-sociohistoric tradition.

The *behaviorist/empiricist* tradition includes associationism, behaviorism, and connectionism. According to this view, mathematical knowledge and skills are the result of an accumulation of acquired associations and skills. A classic example of this tradition is Thorndike, who applied his associationist view on learning (as differential strengthening of associations by reinforcement) to the learning of arithmetic. Although this tradition plays a minor role in contemporary research, its ideas still permeate into current instructional practices, for example in drill-and-practice approaches. Conceptions of mathematics as providing correct answers to well-defined mathematics tasks, of learning mathematics as incremental (with errors to be avoided or immediately stamped out), and of mathematics teaching as the reinforcement of mathematically correct responses, remain prevalent in many current instructional practices and, as such, represent the legacy of this first tradition.

The *cognitivist/rationalist* perspective involves research traditions such as Gestalt psychology, symbolic information processing, and constructivism. These traditions conceive mathematical knowledge as universal mental entities situated in individual learners, such as cognitive schemes and procedural rules, and define learning mathematics as changes in these universal mental schemes and rules. Typical representatives of this tradition are Piaget, who theorized mathematical development in terms of the stepwise acquisition of increasingly complex logico-mathematical structures; Wertheimer, who emphasized the insightful detection and exploitation of structure in mathematical thinking and learning; and information-processing theorists such as Resnick and Siegler, who performed fine-grained analyses of the cognitive structures and processes involved in the acquisition and use of key mathematical concepts and skills.

The *situative/pragmatist-sociohistoric* perspective entails traditions such as ethnography, anthropology, and situation theory. This third framework embraces all those theories that view mathematical learning as a reorganization of activity that accompanies the integration of an individual learner within a "community of practice." Having its origins in Vygotsky's work, this third tradition emerged strongly in the late 1980s in reaction to the then dominant cognitive view of mathematical learning as a highly individual and purely mentalistic process of knowledge and skill acquisition occurring in the learner. In contrast to this cognitivist view, the situated perspective stresses that mathematical learning is enacted essentially in interaction with social and cultural contexts and artifacts, and especially through participation in cultural activities and contexts. Whereas in the cognitivist view, mathematics is seen as a universal knowledge system, the situative/pragmatist-sociohistoric perspective assumes that mathematics differ according to the setting in which it has been developed and in which it is practiced.

Important Scientific Research and Open Questions

The Goal of Mathematical Learning: Acquiring Mathematical Competence

Whereas it was for a long time quite common to think of mathematical competence as the mastery of specific knowledge and skills, it is now generally agreed that it involves a broad set of competencies including: (a) a well-organized and flexibly accessible domain-specific knowledge base, (b) a set of problem-solving methods (heuristics), (c) metacognitive knowledge and self-regulatory skills, and (d) affective components involving beliefs, attitudes, and emotions vis-à-vis mathematics and its learning and teaching.

This broad conception of mathematical competence is nicely reflected in the characterization of "mathematical proficiency" in the report of the National Research Council (2001), *Adding it up*, wherein proficiency is defined in terms of five strongly interwoven strands, namely:

- Conceptual understanding, comprehension of mathematical concepts, operations, and relations
- Procedural fluency, skill in carrying out procedures flexibly, accurately, efficiently, and appropriately
- Strategic competence, the ability to formulate, represent, and solve mathematical problems
- Adaptive reasoning, the capacity for logical thought, reflection, explanation, and justification
- Productive disposition, a habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's efficacy

Research in mathematical subdomains, such as whole number arithmetic, algebra, geometry, statistics, etc., contains numerous illustrations of the importance and interdependency of these different strands of proficiency (see, e.g., Grouws 1992; Lester 2007).

Mathematics Learning

In line with the above broad conception of mathematical competence, it is now quite generally agreed that mathematical learning is not a one-dimensional phenomenon; as it proceeds, each strand of mathematical proficiency develops in interaction with the others. Moreover, research over the past decades has resulted in the view of mathematics learning as the active and cumulative construction of mathematical proficiency – constrained by the structural and functional properties of the human cognitive architecture, and situated in a given community of learners and a broader sociocultural context.

The view that learning is *an active and constructive process* is now common ground among mathematics educators and is supported by substantial empirical evidence. Essentially, mathematical competence is seen as the result of the mindful and effortful involvement of the learner in the processes of knowledge and skill acquisition in interaction with the environment, rather than the result of direct information transmission. This involvement is well illustrated in children's invented idiosyncratic but accurate procedures for solving arithmetic problems in and out-of-school contexts. However, the constructive nature of learning is also expressed in a negative way in the misconceptions (such as the idea that "the area of a square increases by 10% if its sides are increased by 10%") and defective procedures (such as, in multidigit subtraction, subtracting in each column the smaller digit from the larger) that many learners acquire.

Mathematics learning is also *cumulative*. This refers to the pivotal role of prior knowledge, which can affect learning in both positive and negative ways. There is ample evidence that children's thinking about number relies on certain core principles or presuppositions that are based on their experience with natural numbers. This facilitates some kinds of learning but inhibits others. For example, this early understanding of natural number and its properties strongly supports children's conception of multiplication as repeated addition, while at the same time it leads to the misconception that multiplication always leads to a bigger result, or that every number has a number immediately preceding it (Vosniadou and Verschaffel 2004).

Furthermore, mathematics learning is *constrained by the human cognitive architecture*, i.e., the manner in which our cognitive structures are organized in memory and our information-processing system works. Most treatments of the human cognitive architecture use the sensory memory/working memory/long-term memory model as their base. The characteristics of working memory and long-term memory and their functional relations (e.g., the fact that, when processing novel information, working memory is very limited in duration and in capacity) determine the quantity and quality of what will actually be learnt (Kirschner et al. 2006).

Finally, mathematics learning (and mathematics as such) is also a *situated* activity, which means that it is enacted essentially in interaction with social and cultural contexts and artifacts, especially through participation in sociocultural activities and communities. The outcomes of a large series of ethno-mathematical studies of the informal calculation procedures, problem-solving strategies, and learning mechanisms of particular groups of children and adults involved in everyday cultural practices, such as tailoring, weaving, carpentry, navigating, grocery, packing, cooking, etc., has largely contributed to the popularity of this viewpoint. Although the situated nature of doing mathematics and of mathematics learning has been documented especially well within such out-of-school contexts, it is obvious that this situatedness also applies to mathematical learning in school. For instance, the numerous examples of students' "suspension of sense-making" when doing school word problems (leading to computationally based solutions to absurd problems such as in "There are 26 sheep and 10 goats on a ship. How old is the captain?" Answer: $26 - 10 = 16$) can be considered as evidence for the importance of the situatedness of mathematical cognition and learning (Verschaffel et al. 2000). From an educational perspective, the situativity view particularly implies the importance of interaction and collaboration in mathematical learning. This view also stresses that mathematics should be taught in close relation to meaningful contexts in which it will be finally used. Mathematics educators have broadly embraced the view that learning is not an internal solo activity; rather learning efforts are distributed over the individual learner, his/her partners in the learning environment, and the representational tools and technological resources that are available.

Instruction

For a long time, mathematical learners received school-based instruction according to a traditional "skills approach" – an instructional approach that is based on the view that mathematics learning is a highly individual activity consisting mainly of absorbing and memorizing a fixed body of fragmented and decontextualized knowledge and procedural skills directly transmitted by the teacher. Against the background of the above-mentioned view that mathematical proficiency comprises the integrated mastery of various kinds of competencies and that mathematics learning is an active, cumulative, and situated process of knowledge building and skill acquisition, many researchers and practitioners have criticized this traditional "skills approach" and pleaded for reform-based instructional approaches, which aim at the mastery of all aspects of mathematical proficiency and which are characterized by more meaningful and inquiry-based (or problem-based) forms of learning. A classic example is the so-called realistic mathematics education approach (Freudenthal 1983). Although there is evidence in favor of these reform-based approaches, this evidence is not always entirely positive. There is still a lot of debate among mathematics educators nowadays about the goals, the content, the teaching methods, and the assessment tools for mathematics education. This is illustrated by the ongoing "math wars" between "traditionalists" and "reformers" in various (Western) countries.

Cross-References

► Competence
► Conceptual Change
► Constructivism
► Mathematical Models / Modeling in Math Learning
► Mathematics Learning Disability
► Situated Cognition

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Mathematical Linguistics and Learning Theory

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Synonyms

Algorithmic learning theory; Computational learning theory; Formal language theory

Definition

Mathematical linguistics refers to the use of rigorous mathematical frameworks to model aspects of languages, either natural or formal.

Learning theory refers to mathematical modeling of learning and inductive inference.

Theoretical Background

Mathematical Linguistics

Traditionally, the subject of mathematical linguistics was essentially equivalent to *formal language theory*, which was initiated chiefly by Noam Chomsky's early work in the late 1950s. Precursors to this work included that of Alan Turing, and also Emil Post, on the theory of computability in the 1930s, and work on defining grammars by Axel Thue as early as 1906. A formal language is normally defined as a set of expressions, or sentences, consisting of elements drawn from a vocabulary. One standard terminology refers to the vocabulary as an *alphabet*, with the sentences then being called words, but it makes no difference to the underlying theory. The theory of formal languages is mostly concerned with finite means of generating (i.e., describing) languages having an infinite number of sentences from a finite vocabulary, and with studying the properties of classes of languages so generated. Given any finite vocabulary V of sufficient size, a standard hierarchy of formal language classes, ordered by complexity of the language definitions, is called the *Chomsky hierarchy*. The classes in the hierarchy are the finite, regular, context-free, context-sensitive, and recursively enumerable languages. The lowest member of the hierarchy literally includes all finite languages using V, so that all higher classes contain infinite languages. The recursively enumerable languages are thought to encompass all computable languages, so this class is maximal in an interesting sense.

Formal language theory is entirely concerned with the *syntax* of languages, which amounts to describing which sequences of words are allowed as sentences. In any application, however, a language serves some meaningful purpose, and so it is important for mathematical linguistics to include approaches to *semantics.* The mathematical study of the semantics of languages is historically connected to formal logic, chiefly through the intermediary of *type theory.* In a typed language, every element of the vocabulary is assigned to a category called a *type* in some fashion. The set of types is most commonly infinite, and is usually derived from a small set of *primitive types* (e.g., {e,t}) by an inductive definition including all other types representing functions mapping one type to another (e.g., $t \leftarrow e$ and $(t \leftarrow e) \leftarrow e$). In the preceding notation, the functional map is represented by the arrow, which may be read as *from.* In one popular type theory for the semantics of natural languages (that of Richard Montague), proper noun denotations are assigned to a type e of entities, while sentence denotations are assigned to type t of truth-values. Then one may proceed by recognizing intransitive verbs as denoting elements of type $t \leftarrow e$ because they semantically yield a truth-value when provided with the subject entity.

In the 1930s, Alonzo Church developed a system now called the λ-calculus for investigating formal logic and the foundations of mathematics using a calculus of terms which could represent both objects and functions among them. In 1940, Church presented the *simply typed* λ-calculus as a modification in which all the terms of the system were assigned to a type in the fashion described above. It is this typed system that has proven to be most useful in the presentations of logical deductive systems which are capable of representing meanings in a manner relevant to both linguistics and language theory in computer science. Terms of the typed λ-calculus can represent the meanings of complex expressions in artificial or natural languages in *compositional* fashion, so that complex meaning terms are directly composed out of simpler terms in a manner which can be directly connected with the syntactic composition of words in a formal language. In order to be adequate for natural language semantics, however, the typed λ-calculus is not enough; it needs to be extended to an *intensional* system in which expressions have a *sense* as well as a denotative meaning. Church himself proposed numerous variations of an intensional λ-calculus over nearly 50 years beginning in 1946, but it was the intensional λ-calculus put forth by Richard Montague in several papers around 1970 that became the standard for studying the semantics of natural language mathematically.

An alternative to rewriting grammars for specifying formal languages syntactically is provided by *categorial grammar,* in which vocabulary elements are assigned to one or more syntactic types in a type theory. It is then possible to apply one word to another in a functional manner, analogous to the λ-calculus above, in order to derive that some combination of words is a sentence. In the brand of categorial grammar known as *type-logical grammar,* the analogy with λ-calculus is literal, so that word combinations are actually proven to be sentences in a logical system of types using rules that parallel the rules of λ-calculus. The advantage of such an approach, despite its formal complexity, is that the syntax-semantic interface between a type-logical grammar and λ-calculus meaning terms is obtained "for free," without the need for syntax-semantics correspondence rules to be stipulated.

For more information, readers are directed to the books by Partee et al., by Kracht, and by Kornai. Mathematical linguistics now extends to morphology and phonology should readers wish to pursue those topics elsewhere.

Learning Theory

The first formal paradigm for investigating language learning was codified by E. Mark Gold in a 1967 paper, and is usually referred to as *identification in the limit (i.i.l.).* In this framework (see Jain et al. 1999, for more information), a learner is modeled as a device which receives an ever-increasing amount of data from language L, and in response it keeps proposing languages that it might be observing. Such a learner is held to have learned a (potentially infinite) formal language L (within some *hypothesis class*) from a finite data sequence drawn from L just when its sequence of hypothesized languages drawn from the hypothesis class eventually settles upon L (in the limit) and does not change hypotheses any longer. In practice, learners of this sort that have been described usually perform *grammar induction,* whereby a formal grammar which generates the learning data (or *text*) is constructed in some fashion that allows further generation of sentences in a hypothesized language beyond the learning data. Such a process can be seen as a model of human language learning, wherein a child learning Spanish, for example, does not have to hear every Spanish sentence before effectively learning Spanish. It is generally presumed possible (given the evident abilities of humans) to induce a correct grammar generating Spanish (presumed to be at least potentially infinite if not actually so) from a mere subset of Spanish, operating within a hypothesis class that is naturally limited to the possibly human languages.

Gold started a small furor when he proved that no hypothesis class of formal languages (over a given vocabulary) that includes the finite class plus even so much as one infinite language is identifiable in the limit from sentence data only – meaning none of the languages in the class is *i.i.l.* It is important to emphasize, however, that Gold's theorem is inapplicable whenever the hypothesis class does not include all finite languages over the given vocabulary. Since it would seem very strange to propose that the hypothesis class that should model the possibly human languages (over a given vocabulary) contains all finite languages over the vocabulary, it has since been realized that Gold's result is not generally relevant to the capabilities of formalized language learners that could serve as models of natural language learning.

The other important framework in formal learning theory that has been applied to linguistics is really a family of related frameworks under the rubric of *statistical learning theory* (see Niyogi 1998, for more information). One prominent example is the *probably approximately correct (PAC)* model of inductive inference, which was introduced by Leslie Valiant in a 1984 paper. In this approach, learning of a target language is characterized as hypothesizing, with high probability and in a computationally tractable amount of time (specifically, in *polynomial time* as a function of the amount of learning data), a language that is a good approximation to the target in a well-defined sense. One difficulty with applying the PAC learning framework, and other statistical frameworks, to the modeling of language induction stems from the complete lack of probabilistic notions in basic mathematical linguistics as described above. In order to deal with formal languages using statistical concepts, it is frequently necessary to introduce probabilities into the formal language model somehow, to give some meaning to the notion of the "probability of a sentence." One way of doing this (exemplified in recent work by Alex Clark) involves assigning probabilities to the rewriting rules in a grammar, thereby yielding a *probabilistic grammar.*

Important Scientific Research and Open Questions

Perhaps the most fundamental problem for mathematical linguistics is to delineate the class of possible human languages. It is assumed that this class includes no finite languages. Moreover, all natural languages are thought to be at least context-free, and there is reason to believe that some may be context-sensitive. Beyond these basic conditions, there is much more to be nailed down, since obviously most context-free languages are not possibly human. It is likely that conditions on the relationship between syntax and semantics are going to form a part of our ultimate specification.

Research on natural language semantics has recently moved beyond the intensional framework of Montague, but there is no consensus on the best approach to semantics as yet. No system of intensional logic has yet been developed which is entirely adequate for modeling natural semantics, and many researchers have chosen to develop other frameworks which do not use an intensional logic directly.

One important research topic which is unfortunately absent from mathematical linguistics is the modeling of *morphosyntax*, which would account for morphology (word structure) and its relationship with syntax and semantics.

Progress in formal learning theory will require refining our models of language learning to develop a tractable and realistic learning algorithm. There are currently parallel developments in the *i.i.l.* paradigm and the statistical paradigm making progress on this. One point of debate in mathematical research on language learning concerns just what sort of information should be presented to the learner along with the sentences of the language. One hard-line position (often considered a null hypothesis) has been that a model learner of natural language should be limited to the sentence text; this approach has been characterized as learning from pure string data. Some researchers, however, have instead assumed that more information (such as meaning terms or sentence structures) should be provided to accompany each sentence in the learning data. This position is generally supported by pointing to purportedly self-evident features of human language acquisition, in which a child learner hears sentences in a natural setting accompanied by experiences which impart some information about the intended meanings.

Machine learning refers to the research area concerning computer software which learns a task. Where machine learning has been applied to linguistic tasks, it has not often been applied to the larger task of learning a natural language grammar per se, although the class of regular languages in the Chomsky hierarchy has been tackled with several learning algorithms. Most machine learning algorithms applied to language are statistical in nature, and so seek to learn some kind of statistical language model which may not bear much relation to a linguistic grammar. Formal theorems about learnability are rarely important in the machine learning community, since practitioners are chiefly concerned with what software accomplishes rather than what it could theoretically do, although some researchers have used machine learning techniques to test the theoretical results of formal learning theory.

Formal learning theory has not found application in the area of second language acquisition. This is because most scientists believe that a model of inductive inference would not be correct for second language learning by adults, because second language learning usually proceeds by involving direct instruction and rote memorization, which stray beyond the boundaries of purely inductive inference. The capacity for adults to learn language by inductive inference similar to that performed by a child is rather doubtful.

Cross-References

- ► Formal Learning Theory
- ► Grammar Learning
- ► Inductive Reasoning
- ► Learning Algorithms
- ► PAC Learning

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Mathematical Modeling

► Mathematical Models/Modeling in Math Learning

Mathematical Models

► Computational Models of Classical Conditioning

► Mathematical Models/Modeling in Math Learning

Mathematical Models/ Modeling in Math Learning

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Synonyms

Mathematical modeling; Mathematical models; Model eliciting activities; Modeling; Models

Definition

Educational researchers describe a *conceptual system* as a collection of elements, relations, operations, and rules that govern interactions (Lesh and Doerr 2003). *Modeling* is a process for symbolically representing conceptual systems given a specific purpose such as building, explaining, or predicting within a context (Lesh and Doerr 2003). *Mathematical models* primarily articulate structural aspects of conceptual systems that are described using quantitative (and often qualitative) data and meet specific criteria. *Model eliciting activities* are contextually situated problems for which modeling solutions are devised to meet specific criteria for specific purposes; moreover, these solutions or models are developed so that they are readily communicated and recyclable. That is, mathematical models must be shareable and modifiable so they may be used for building, explaining, predicting, or controlling systems in the given context or another (Lesh and Doerr 2003). An example of a mathematical modeling cycle or model eliciting activity that is typically used with middle-grade students is the Bigfoot problem, students are asked to create a model (an approach and rationale for finding the height of a person given a footprint) situated in a context. The selected context should enhance interest for the children, such as the footprint was left by someone who saved a drowning child and the parents wish to pay a reward. The modelers interpret the situation using extant mathematical understanding and other available resources to generate a model, and then they defend their models publicly among their peers. This public sharing creates opportunities for students to reinterpret understandings and may lead to model revisions.

Theoretical Background

The models and modeling (M&M) perspective of learning is related to constructivist theory, yet it goes beyond constructivism and offers a measure of practicality for teachers, curriculum developers, researchers, and teacher educators (Lesh and Doerr 2003). In general, constructivists agree that learners construct meaning or knowledge and their understandings are not received passively from others (Steffe and Kieren 1994; Cobb and Yackel 1996; Ernest 1996). An M&M perspective on the acquisition of knowledge is comprised of many relevant processes and constructing understanding is only one. Other important processes from an M&M perspective include determining relevant information, prioritizing criteria by importance, integrating new criteria, or restructuring representations for a new audience.

An M&M perspective supports that some knowledge must be constructed, sometimes existing constructs require interpretation or reinterpretation, and some knowledge is transferred (e.g., skills, established notation, and accepted mathematical procedures). Assumptions from the M&M perspective include: (a) people create meaning from their experiences using models; (b) models allow understandings to be communicated using many representations through different interactional media; and (c) models are continuously interpreted and reinterpreted. One might conclude that the M&M perspective is a manifestation of thinking externally and contextually situated.

Mathematical Modeling for 21st Century Learning

This century is emerging as an information age, and technological advances have been and are anticipated to be immense; however, mathematics and science teaching and learning within classrooms has not evolved similarly. The modern world economy is impacted by a myriad of complex systems (e.g., transportation systems, resource management and distribution systems, social networks, simulation systems, etc.); however, most mathematics and science classrooms are not designed to expose students to or to create opportunities for modeling such systems. Researchers have concluded that there are significant similarities between student-developed models and those of mathematicians and scientists (Lesh and Doerr 2003; Lesh and English 2005). Thus, one must question why curricula and pedagogies are not more focused on creating opportunities for students to develop models for representing the complex systems of the world or to consider ways for improving systems when students appear to have sufficient conceptual tools and representational formats for grappling with such problems.

Problem solving in many mathematics classrooms is characterized by contextual situations that are unrelated to student experiences, limited interpretive freedom, and problem meaning/solutions determined by others. Fueled in part by pressures for state mandated testing, too often classroom-based problem solving is little more than applying practiced procedures and skills and requires little cognitive demand from students. In contrast, the M&M perspective of mathematics is developing mathematical understanding through modeling conceptual systems. Students engaged in model eliciting activities describe structural aspects of conceptual systems mathematically, but in ways that are understandable and reusable, a significantly more cognitively demanding endeavor when compared to traditional problem solving. Accountability measures must transition from measuring student proficiency with skills and procedures to their ability to interpret, develop, and explain models situated in different contexts (Lesh and English 2005).

Solutions or models emerge from iterative cycles of modeling until a refined version is deemed acceptable by the learning community. The modeling cycle includes four phases – description, manipulation, translation, and verification (Lesh and Doerr 2003). The description phase establishes a mapping from the contextual situation to the modeling representational space. As the model emerges, manipulation refers to testing the model to refine functionality based upon actions or processes of the system. Translation, another level of testing to refine predictability based upon the contextualized situation. Finally, verification determines if the model is a reasonable representation of the system and meets the specific requirements of the contextual situation.

Important Scientific Research and Open Questions

There are many studies about M&M involving contexts situated in science, technology, engineering, and mathematics (STEM) problems. The domains studied vary, several trajectories include model quality and effectiveness, implications of M&M for learning and related theory, and M&M processes (Chamberlin and Moon 2005; Lege 2005; Pauli et al. 2007; Yarinovsky and Kangro 2009). M&M research is done using a variety of methodologies including experimental, developmental, and ethnographic, but new methodologies are emerging, such as multi-tiered design experiments (Lesh and English 2005). For example, students, teachers, and educational researchers are developing and learning from M&M, each modeler has their independent rationales for modeling, but all models are subject to reinterpretation and revision. These researchers suggest that the model reinterpretation and revision is the apex for thinking and learning because existing understandings are communicated, tested, and revised with each modeling cycle.

According to key researchers in the field, there are many opportunities for studying M&M such as investigating the differences in the ways students engage in modeling, how knowledge development manifests from modeling, the nature of the knowledge developed, and the effectiveness of processes related to M&M (e.g., Lesh and Doerr 2003; Lesh and English 2005). Additionally, research is needed to study existing models and the ways they are refined to understand how they change over time and in complexity. These research trajectories are not suggested for bringing order so student learning may be managed and directed; such studies contribute to more nuanced understandings about how learners develop mathematical and scientific understandings and the processes they use to inform teaching practice and improve the development of more effective modeling opportunities in classrooms and other settings.

Cross-References

► 21st Century Skills
► Case-Based Inquiry Learning
► Constructivist Learning
► Experiential Learning Theory
► Problem Solving

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Mathematical Models/Theories of Learning

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Synonyms

Artificial intelligence (AI); Computational intelligence (CI); Language acquisition; Natural language learning; Pattern recognition

Definition

Theories of Learning (TL) include mathematical theories and techniques for developing algorithms, software, and hardware enabling computers to learn. Some techniques are designed to learn from structured data (called learning or training data), examples of objects or situations of interests; these might be given along with labels, for example, an image of an object, say chair, is given along with a label "chair." This is called learning with a teacher. Learning without labels is more complicated. The most advanced techniques learn from unstructured, unlabeled sensor data in real time. Subareas of TL include pattern recognition, image understanding, and language learning (speech or text). AI in narrow sense is reserved for computational intelligence techniques based on coded rules and procedures without learning; in a wide sense it includes TL. TL is an active area of research. Successful TL techniques are currently limited to narrow specific fields. Existing TL are much less powerful than animal or human learning abilities. Therefore, most advanced current approaches are biologically inspired or cognitive algorithms. Their development is facilitated by recent progress in understanding biological learning mechanisms as well as by breakthroughs in mathematics of TL.

Theoretical Background

TL were initiated almost as soon as computers became available in the early 1950s. Many developers of TL were sure that computers would soon surpass by far human minds in their abilities. Human brain cells, neurons, learn by modifying strengths of their connections, synapses. This is called Hebbian learning (1949). Based on this idea in the 1950s, Rosenblatt developed "Perceptron," a mathematical model of a neuron. Developments in this and related directions are currently named "early neural networks."

In parallel, statistical approaches to learning were developed (Nilsson 1965; Duda and Hart 1973), which received a name "pattern recognition" (PR) The main idea of statistical PR was (1) to characterize objects of interest by a set of "features" (say, color, size, etc.); features form coordinates of a feature space or classification space, where objects are points; and then (2) develop a mathematical algorithm that partitions classification space into regions, corresponding to classes of objects. Some of these algorithms are used till today, for example, a linear classifier (a linear combination of features makes a line that divides the space into two parts), a quadratic classifier, or a nearest neighbor classifier (a class is defined by neighborhoods of selected samples).

Learning abilities of Perceptrons turned out to be very limited (Minsky and Papert 1969/1988). Learning abilities of PR were also limited by the number of features that could be efficiently used (the dimensionality of a feature space could not be made much more than 7 or 8). This problem was named "the curse of dimensionality" (Bellman 1961). A group of scientists (McCarthy, Newell, and Minsky) concluded that developing learning machines was premature, a more efficient approach to building intelligent machines was to program into machines readymade knowledge about a particular area of engineering. This approach was associated with the name "Artificial Intelligence" (AI). Knowledge coded as systems of if-then rules (if A then B) achieved many practical successes. Rules were laboriously elucidated from experts in a field and called an expert system. Today this approach is referred as "rule systems." Rule systems were efficient, when environment and tasks did not change. When conditions vary, learning was required, yet many attempts to combine rules with learning failed.

In the 1980s, model systems were proposed (Nevatia and Binford 1977; Brooks 1983; Grimson and Lozano-Perez 1984) for combining knowledge and learning. Knowledge was encapsulated into models (of objects or processes); these models depended on parameters, and values of parameters were learned from data for a particular situation. In parallel, a second wave of neural network paradigms was developed inspired by studying brain architecture (Grossberg since 1950s, see 1970, 1982), ART neural network emphasizing interaction of bottom-up and top-down signals (Carpenter et al. 1992) and backpropagation algorithm (Werbos 1974). New algorithms overcame limitations of the early neural networks. Mathematical modeling of the mind became a fascinating direction. Yet, modeling human or even mouse learning abilities was nowhere in sight.

Evolutionary algorithms (EA) are an approach to TL, which models genetic evolution, rather than mechanisms of the mind-brain (Holland 1975/1992). It offered an approach to learning-optimizing problems involving discrete constructs or models, which could not be at the time described by continuous functions, and which could not be approached by other existing methods. The main principles of EA are (1) to describe a discrete system by a list of its components, similar to how DNA describes an organism; (2) evolve better systems by (i) random mutations, (ii) sexual crossover, and (iii) fitness selection. Limitations of EA are related to the fact that genetic mechanisms are poorly known; the described principles are likely a poor model of genetic evolution. EA is a fascinating research field, with concrete engineering applications. Yet, the nature uses different mechanisms for genetic evolution and for learning in the mind. This suggests that EA may be not the best for TL, not the right way to model the mind and approach its learning abilities.

TL approaches to language originated in the 1950s (Chomsky 1972). They paralleled other ideas in TL, rule systems, model systems (or what Chomsky called principles and parameters, 1981). Chomsky postulated that language is a separate system from cognition. Cognitive linguistics attempts to unify language and cognition. Evolutionary linguistics (developed since the 1980s by Steels, Hurford, Kirby, and others) emphasizes that many properties of language can be understood, when considering language as an evolving system, transmitted from generation to generation.

In the 1990s, mathematical difficulties of thousands of learning algorithms, briefly overviewed above, were understood as related to a single principle of combinatorial complexity (CC) of learning (Perlovsky 1998, 2001). CC was a result of combinations inherent to learning or training procedures. During training, every object had to be "shown" to a neural network or learning algorithm in all variations (of size, distance, view angles, etc.), but also training had to include these object variations in *combinations* with any other object that could be around. CC is unsolvable because even a modest number of 100 elements (objects, pixels, samples, etc.) result in 100^{100} combinations; this number is larger than all elementary particle interactions in the entire history of the Universe. No computer ever would be able to learn that many combinations. CC was related to a most fundamental mathematical result of the twentieth century, Gödelian limitations of logic (Perlovsky 1996, 2001). CC turned out to be a manifestation of Gödelian "incompleteness" of logic in a finite system (a computer). All considered TL approaches rely on logic in some essential steps: To accommodate training, rule systems had to grow combinatorial trees of rules, model systems had to consider combinations between data and models, statistical pattern recognition faced the curse of dimensionality, and all algorithms faced combinatorial training procedures. This applies even to approaches specifically designed to overcome logical limitations, such as neural networks (second wave) and fuzzy logic. Hundreds of TL algorithms are developed every year, yet without understanding these fundamental limitations, progress toward generally applicable TL is limited. So far, most of existing algorithms succumb to limitations of CC. Performance of TL algorithms in many applications is limited by the number of computer operations, not by the amount of potentially available information (Cramer–Rao Bounds).

TL approaching animal and even human abilities currently proceeds due to breakthroughs in mathematics and neurocognitive understanding of the brain mechanisms. Below we summarize one successful approach, dynamic logic (DL) also called Neural Modeling Fields (NMF) (Perlovsky and McManus 1991, Perlovsky 2001). DL-NMF uses parametric models, like model systems. DL-NMF is a process-logic, in which uncertainty of models (or measures of fitness between models and data) matches deviations of model parameters from their true values. The DL-NMF process evolves vague-fuzzy models with incorrect parameter values into crisp models with correct parameters. (It is interesting that Aristotle similarly described working of the mind: Forms-as-potentialities evolve into forms-as-actualities; potentialities are not logical, actualities obey logic, Perlovsky 2006). This dynamic process overcomes fundamental limitations of static classical logic. DL-NMF overcomes CC because combinations (between data and models) need not be considered: Initially all data fits any model, because of the model vagueness. At the end of the DL-NMF process, all data are correctly assigned to their models. The DL-NMF process is illustrated in Fig. 1.

Similar process was demonstrated to take place in the brain during human perception (Bar et al. 2006). During visual perception, mental representations of objects (models) are fit to retinal images of objects projected to the visual cortex (data). This fitting process takes about 160 ms. Initial representations are unconscious and vague, as in DL-NMF. Conscious perception occurs when representations-models become crisp and fit data.

DL-NMF applications were developed in many fields. DL-NMF algorithm performance often approaches information-theoretic limits (Cramer–Rao Bounds), and exceeds past algorithms by an order (or several orders) of magnitude.

Important Scientific Research and Open Questions

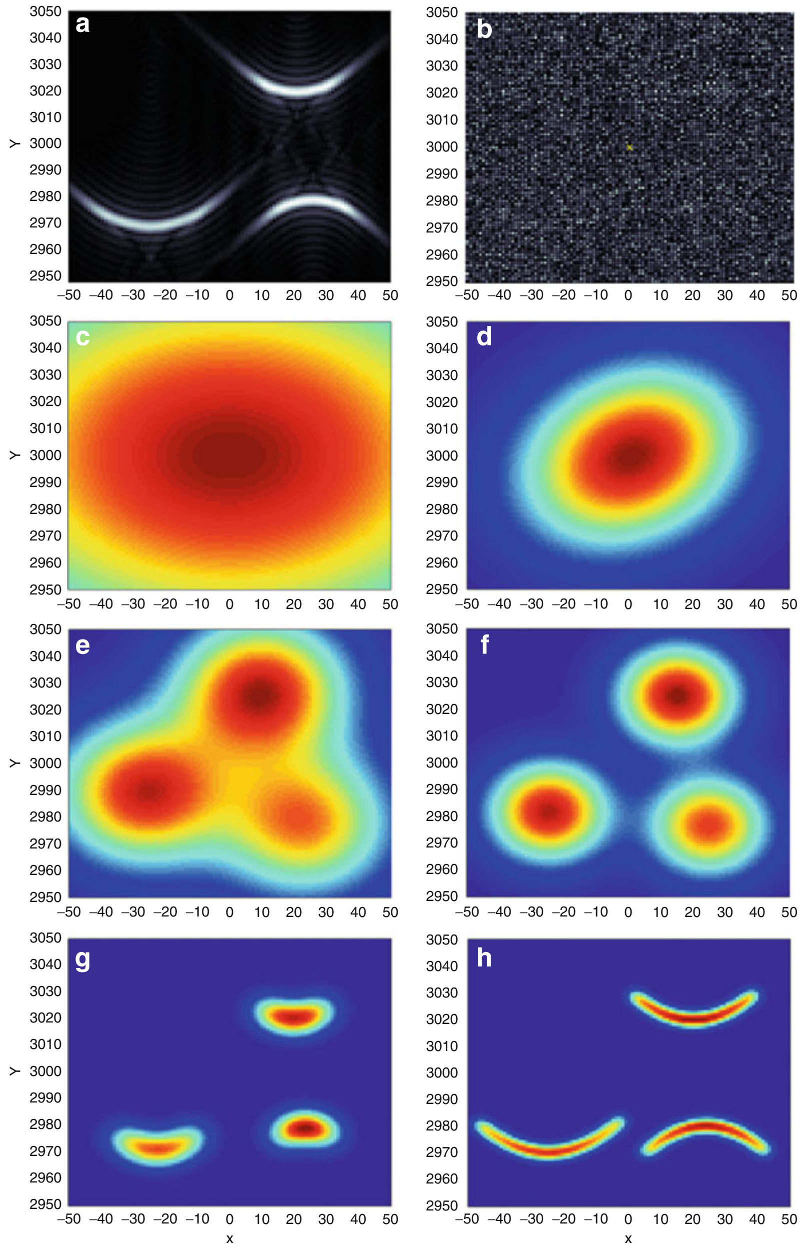
TL major paradigms reviewed in the previous section, developed since the 1950s, are still in current use in practical engineering applications. Rule systems and statistical pattern recognition have clear intuitive appeal. It is becoming clear however, that appeal to consciousness implies classical logic along with its inherent limitations. On the road to human-level TL an open question to be addressed is to overcome appeal of intuitive logical algorithms and to combine mathematical and engineering developments with neurocognitive findings about mechanisms of the brain-mind.

Developing mathematics corresponding to brain-mind mechanisms opens most fascinating research directions in TL. Whereas combining molecular biology with physics has opened new research fields for the last half century, combining physics and mathematics with brain imaging and neurocognition will play a similar role in the next half century. New TL techniques are developed by further advancing DL by combining it with other TL algorithms and with new neurocognitive findings.

A major TL research direction is finding mechanisms of interaction between cognition and language. Human-level cognition exists only in combination with human language. Psychological studies of prelinguistic infants demonstrate that their cognition is no different from animals' (Carey 2009). Human cognition requires language. Emerging TL directions emphasize that language learning is grounded in surrounding language at all hierarchical levels, from sounds to words, phrases, syntax, extended pieces of text, etc. Language models therefore are acquired "readymade," and language is learned by 5 years of age. Learning cognitive models requires real-world experience. Experience alone, however, is not sufficient; no amount of experience would be sufficient to learn useful *combinations* of events and actions among many more random combinations, having no use or meanings. Whereas learning perception is *grounded* in observing objects, learning higher-level abstract cognitive models is not grounded in what can be directly perceived. Therefore, learning higher-level cognitive models, "above" perception of objects, can only proceed guided by language.

Another fundamental TL research direction addresses hierarchical learning systems. The mind-brain is organized into an approximate hierarchy. In this hierarchy, concept-models receive higher meanings at higher levels (synthesis), while higher-level concept-models differentiate into more detailed and specific meanings at lower levels. Mathematical techniques should be developed for learning such a hierarchy of interacting levels, with synthesizing function propagating up the hierarchy and differentiating function propagating down. From the previous paragraph it is clear that not one but two interacting hierarchies should be modeled, for cognition and for language. Learning this dual hierarchy, with language hierarchy grounded in the surrounding language, and cognitive hierarchy grounded in experience and guided by language is a challenge for TL. In this future development what would be the role of the process "from vague to crisp"? It is likely that language learning quickly proceeds to crisp states at all hierarchical levels, whereas cognitive models at higher levels of the hierarchy remain vague until experience is accumulated in correspondence with language. TL cannot proceed driven by mathematics alone; it should proceed along with psychology and cognitive science.

The role of emotions in learning is another fundamental direction in future TL. While TL was organized around logically based algorithms, the role of emotions could have been ignored, emotions were modeled just



Mathematical Models/Theories of Learning. Fig. 1 Finding "smile" and "frown" patterns in noise, an example of DL-NMF "from vague-to-crisp" process: (**a**) true "smile" and "frown" patterns are shown without noise; (**b**) actual image available for recognition (signal is below noise, signal-to-noise ratio is about 1/3); (**c**) an initial fuzzy blob-model, the vagueness corresponds to uncertainty of knowledge; (**d**) through (**h**) show improved models at various iteration stages (total of 21 iterations); a noise model is not shown. Between stages (**d**) and (**e**) DL-NMF tried to fit the data with more than one model and decided that it needs three blob-models to "understand" the content of the data. Until stage (**g**) the algorithm "thought" in terms of simple blob-models, at (**g**) and beyond, the algorithm decided that it needs more complex parabolic models to describe the data. Initial models are vague (contain low-spatial frequencies compared to the final one). Iterations stopped at (**h**), when similarity between models and data stopped increasing. This example exceeds previous algorithm performance by two orders of magnitude in signal-to-noise ratio. Complexity is reduced from combinatorial 10^{5000} (logical search) to 10^9 (DL-NMF) like other logical rules. Future TL development would have to model emotional mechanisms of the human brain-mind. The word "emotion" is used for many different functions. One of these functions crucial for future TL development is based on Grossberg–Levine theory of instincts and emotions (1987). This theory suggests that instincts can be modeled as sensors, indicating basic needs to the body. Emotions are modeled as signals connecting instinctual mechanisms ("sensors" of basic needs) with learning of concept-models (of objects, events, actions). Emotions impart instinctual values on objects and events; more valuable events receive more attention and more learning resources. The most important instinct for TL is an instinct for learning, or the knowledge instinct. This instinct drives learning mechanisms, which match internal models to sensory data about the world. All TL algorithms have some mathematical model of this instinct. Future TL would unify mathematical, engineering, and cognitive–psychological research for adequate understanding of related mechanisms. Emotions related to satisfaction of the knowledge instinct measure correspondence of internal models and patterns in sensory data. These are "higher" emotions in that they address knowledge rather than bodily needs, and they are essential for TL. At higher cognitive levels, they have to involve correspondence of cognitive models (imagery, abstract constructs, and behavior), sensory data and experiences, and contents of language models (words, phrases, syntax, etc.). Modeling these emotions in TL are essential for modeling higher cognitive abilities, which mostly consist in learning abstract cognitive and behavioral models in correspondence with language. Musical emotions resolve contradictions created by cognitive dissonances (Perlovsky 2010). Future TL will have to explore these emerging understandings and reconcile the instinct for knowledge with basic irrationality discovered by Tversky and Kahneman. Combining aesthetic theory of Kant (1790) with TL leads to a conclusion that abilities for emotions of the beautiful should be modeled as satisfaction of the knowledge instinct at the highest levels of the brain-mind hierarchy (Perlovsky 2010). Mental models at these highest levels unify entire experience and create higher-level meanings. Modeling these higher-level human mental abilities is the direction for future TL.

Cross-References

► Adaptive Learning Systems
► Artificial Intelligence
► Bottom-Up and Top-Down Learning
► Cognitive Dissonance

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Mathematics

► Accounting and Arithmetic Competence in Animals

Mathematics Learning

► Mathematical Learning

Mathematics Learning Difficulties

► Mathematics Learning Disability

Mathematics Learning Disability

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Synonyms

Dyscalculia; Mathematics learning difficulties; Mathematics learning disabilities

Definition

Mathematics learning disability (MLD) or dyscalculia is a specific learning disorder in mathematics that has been defined in a similar way as other specific learning disorders, such as dyslexia. MLD involves large and persistent problems in mathematics that are not merely explained by inappropriate instruction, environmental deprivation, and behavioral or emotional disorders. It is assumed that MLD is due to underlying brain abnormalities, which are probably of a genetic origin.

For many years, the predominant model for defining MLD was the IQ-discrepancy model, which indicates that there should be a discrepancy between IQ and performance level in mathematics. The validity of this model has been seriously questioned. Nowadays, the above-mentioned low achievement model is combined with the response-to-intervention model. According to this approach, individuals with MLD show serious difficulties in mathematics achievement and do not sufficiently respond to appropriate instruction and intensive intervention (Fletcher et al. 2007).

Theoretical Background

Numbers and arithmetic are so much a part of our modern life that it is essential for children to acquire basic mathematical competencies. Unfortunately, 3–8% of primary school children show large and persistent difficulties in acquiring these competencies. These difficulties have been referred to as mathematics learning disability, mathematics learning difficulties, or dyscalculia (Berch and Mazzocco 2007). It is important to note that these difficulties are not transitional and continue to exist into adolescence and adulthood. As mathematics is not a unitary skill – it consists of different competencies such as arithmetic, word problem solving, geometry, etc. – children can have, in theory, difficulties in one or more of these components. However, the existing research has focused primarily on elementary arithmetical competencies. Against this background, it is widely agreed that individuals with MLD have difficulties with executing and understanding procedures for solving arithmetic problems and/or retrieving arithmetic facts from long-term memory (Geary 2004). Little is known, however, about more complex mathematics, such as fractions, geometry, and probability.

MLD does probably not represent a homogeneous condition and different subtypes of this learning disorder have been put forward. The most consistent subtypes deal with the presence or absence of coexisting reading difficulties. Prevalence estimates suggest that about two out of three children with MLD have comorbid reading difficulties. Children with MLD without reading difficulties and those with MLD and comorbid reading difficulties have been found to differ in many ways from each other, with children with MLD and comorbid reading difficulties showing more pervasive difficulties, especially in those areas of mathematics that are of verbal nature, such as word problem solving.

Important Scientific Research and Open Questions

While the issue of MLD is getting increasing attention, research in this area is still lagging behind compared to research in other academic subjects, such as reading and language. One of the major concerns of researchers in the field is to characterize the various cognitive processes that are implicated in the development of MLD. This unraveling of the cognitive characteristics of MLD might provide an important basis for designing and realizing effective educational interventions for children with MLD.

Several *cognitive explanations* for the presence of MLD have been put forward. Most of the available research on MLD has dealt with domain-general cognitive factors, such as poor working memory and difficulties with the retrieval of phonological information of long-term memory. More recently, it has been proposed that MLD arises as a consequence of domain-specific impairments in number sense or the ability to represent and manipulate numerical magnitudes.

Studies examining the role of domain-general factors in the emergence of MLD largely focused on *working memory*, showing that children with MLD exhibit poor working memory, particularly central executive function (Geary 2004). This might contribute to difficulties in executing arithmetic procedures, such as difficulties with the monitoring of the different problem solving steps or with keeping track of intermediate results while calculating the answer. The ability to *retrieve (phonological) information from long-term memory* has also been proposed as a domain-general cognitive factor to account for MLD. This ability is impaired in children with MLD and might explain their difficulties with arithmetic fact retrieval (Geary 2004). Because the retrieval of (phonological) information from long-term memory is also implicated in the development of reading difficulties, it has been proposed that it may account for the covariation of MLD and reading difficulties, yet empirical evidence for this hypothesis has been inconclusive so far.

Against the background of findings from neuroimaging research, it has been proposed that MLD arises as a consequence of *domain-specific impairments in number sense* or the ability to represent and manipulate numerical magnitudes (Landerl et al. 2004). For example, children with MLD have particular difficulties in comparing two numerical magnitudes and in putting numbers on a number line, both of which are thought to measure one's understanding of numerical magnitude.

Although various cognitive candidates have been put forward to explain the MLD, the existing body of data is still in its infant state. The current data suggest that there are different underlying mechanisms and pathways to MLD, which fits with the heterogeneity observed in the mathematical difficulties of children with MLD. The available research is, unfortunately, mainly limited to correlational evidence between a particular cognitive factor and mathematics performance. It remains unclear whether these potential cognitive mediators are the source, the consequence, or a non-causally related marker of MLD. Longitudinal research is required to investigate this issue. These studies should focus not only on how impairments develop but also on how compensatory mechanisms start to emerge and how apparently normal abilities might have a different developmental trajectory.

Initial accounts of MLD in the 1970s suggested that MLD was due to *brain abnormalities*. With the advent of modern neuroimaging techniques, researchers have begun to address this issue. There is converging evidence for the existence of a frontoparietal network that is active during number processing and arithmetic (Ansari 2008). Studies that examine this network in children with MLD are currently slowly but steadily emerging. These few studies consistently indicate that children with MLD have both structural and functional alterations in the above-mentioned frontoparietal network, particularly in the intraparietal sulcus, which is the brain circuitry that supports the processing of numerical magnitudes, and the (pre)frontal cortex, which is assumed to have an auxiliary role in the maintenance of intermediate mental operations in working memory. In the next years, this knowledge should be elaborated by longitudinal research that examines the association between abnormal functioning of brain circuitry and classroom measures of mathematical performance that are typically used in educational settings. This will allow us to determine whether abnormal brain activation predicts subsequent mathematical difficulties or whether it is a consequence of poor mathematical achievement.

It has been suggested that these brain abnormalities in children with MLD are probably of a genetic origin, yet the *genetic basis of MLD* remains largely unknown and no genes responsible for mathematics (dis)abilities have been identified. Twin research indicates a moderate genetic influence and the same genetic factors appear to shape individual differences in mathematics in the general population. Studies in the field of medical genetics have revealed that some disorders of a known genetic origin, such as Turner Syndrome and 22q11 Deletion Syndrome, show a consistent pattern of MLD. The study of MLD in these disorders potentially provides an interesting window onto the characteristics of MLD in general and might shed light on the complex interrelationships between genes, brain development, and mathematics performance.

What are appropriate educational *interventions* for children with MLD? Originally, perceptual-motor training was the dominant way of remediating learning disorders, but the effects of this type of training have been discounted. Individualized interventions that target those specific components of mathematics with which a child with MLD has difficulty appear to be the most effective (Dowker 2008). Such intervention involves the assessment of a child's strengths and weaknesses in mathematics and this profile is taken as an input to remediate specific components of mathematical skill. Remediation strategies should comprise a combination of direct instruction and strategy instruction. There is no doubt that these interventions should start as early as possible.

Although the last decade has witnessed a serious growth in research onto MLD, much work remains to be done. Longitudinal research is needed to identify developmental precursors and to delineate developmental trajectories of MLD. The neural basis of these difficulties and their association with classroom performance certainly need to be further explored. Understanding the different characteristics of MLD at different levels, the behavioral, the cognitive and the neurobiological, will inform appropriate educational interventions. The design and evaluation of these remedial interventions needs to be a priority on the agenda for future research. These interventions may not only treat the difficulties, but also prevent them.

Cross-References

► Dyscalculia in Young Children – Cognitive and Neurological Bases
► Learning Numerical Symbols
► Mathematical Learning
► Mental Arithmetic

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Maturation and Learning

► Development and Learning (Overview Article)

Mean-Field Theory of Ensemble Learning

► Mean-Field Theory of Meta-learning

Mean-Field Theory of Meta-learning

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Synonyms

Mean-field theory of ensemble learning; Mean-field theory of meta-learning; Mean-field theory of semiotic landscape formation

Definition

The word *meta* comes from the Greek word "μετά," which means "above," "among," or "beyond." Generally, the meta-learning is the ability to learn how to perform most successful learning. Therefore, meta-learning algorithm changes some aspects of its internal learning procedure, such that the modified learner is able to learn more efficiently, than the original learners. Typically, meta-learning approach is implemented using an ensemble of learning algorithms, similarly to *Reservoir Computing*. Moreover, those learning algorithms are coupled in order to exchange the information about the quality of learned models for a given training example. Such interaction is inspired by famous Hebbian paradigm that *"cells that fire together, wire together."* The parameters of two coupled algorithms are then modified to improve the similarity between them, therefore increase the strength of coupling.

Here, the mean-field theory of meta-learning is defined. The meta-learning equilibration of an ensemble of a diverse set of machine learning, or clustering algorithms is generally very difficult to solve analytically, except for simplified cases. Therefore, in the mean-field approximation the complex system has to be replaced by a population of non-coupled algorithms, with a properly selected external bias. The proposed external bias replaces the coupling between all algorithms by a mean, average the whole ensemble response for a given training example, like in the theory of *Liquid State Machines*. Therefore, many-algorithm's problem is reduced into an effective single algorithm problem with external bias; all couplings are replaced by single instances of machine learning with an average or effective ensemble response to external stimulus. The mean-field model allows obtaining some insights into the behavior of the system at a relatively low computational cost.

Theoretical Background

The term "meta-learning" is used in the information sciences to designate the process, where learning algorithm is constructed in order to properly classify the input training data. Therefore, a meta-learning protocol allows for improving the classification accuracy by modifying the detailed scheme of particular pre-selected classification algorithm. Typically, in machine-learning tasks two sets of objects: *positives* and *negatives* are presented to the classification system. During the learning phase, the statistical model of differences between those two classes is constructed. Further, the machine-learning model is used for making predictions, i.e., to process new objects, by using previously retrieved and stored information organized by the learned model. The prediction phase uses the statistical model for assigning the proper class for new objects, which do not have yet the classification labels.

The meta-learning schema represents the extension of this approach, by allowing the on-demand changes in classification algorithm used to classify training data, when not-optimal learning solution is detected. Therefore, it presents the generic and abstract method to organize the way in which the knowledge is acquired in the course of training sessions. Such meta-scheme organizes the acquired knowledge about specific set of training objects and guides the processing of learning, i.e., constructing statistical model of training information. Therefore, meta-learning can be viewed as structured expectations about principles of learning, which are used for building statistical models for given set of training objects.

The mean-field theory presents a unique way to formalize the meta-learning approach by modeling each learning paradigm as the stationary state of the complex dynamical system. In that way, the meta-learning procedure can be simulated as any physical system, by studying both, the dynamics of phase changes, and the equilibration process. The first analyzes the dependence of available learning solutions on order parameter, and the second studies the trajectory of meta-learning procedure seeking the globally optimal learning solution. Moreover, the perturbation theory can be applied to the system, linking the stability of learned classification model with its surrounding similar solutions in an abstract space of available learning paradigms.

The model of meta-learning is an application of nonlocal cellular automata approach known from physics (Wolfram 1994). The original models, in the context of social opinion exchange, assume the *social* influence decaying with distance. Within this general statistical model the integration of opinion between individual learners (agents) is similar to the dynamical approach of the statistical system to its stationary state. Therefore, the phase transitions can be observed in the system, where the whole system reaches locally a phase change point, emerging the global solution. In our case, the global solution is either uniform, or presenting a variety of clustered minority opinions, within the global sea of majority. This is described here as *integration* of all learning models into the single meta-solution. Changes between phases of the system are induced by some external factors that can be modeled as a bias added to the local fields (minority clusters are free to grow, when they agree with their opinion with the bias value). In that way, the global opinion change can be easily modeled while the external influence changes giving rise to new, global majority in the learning system. This explains the *adaptivity* of the learning algorithm, when the system dynamically responds on the change in the training or input data, allowing for rapid adaptation of the final prediction (e.g., classification outcome). Such adaptivity effect describes the memory of the system, where it preserves the previous solutions not impacting the adaptation to emerged new training data.

The model of meta-learning is based on several assumptions (Plewczynski 2009):

1. Discrete Logic

   We assume digital logic of individual learners, i.e., we deal with cellular automata consisting of N learners, each holding one of several states (e.g., "NO" or "YES" for two class problem) for a given training example. K integer numbers $\sigma_i = 1, \ldots, k$ for the k class problem are used for representing those states. The final meta-classification outcome l for a given training example m is predicted by combining individual prediction results of all machine-learning methods during the consensus phase. We assume simple voting procedure, where the final class l for object m is selected as the majority cluster of similarly predicting algorithms.
2. Quality Estimators

   Three quality estimators characterize each learner: sensitivity $p_i = \frac{\mathrm{TP}}{\mathrm{TP+FN}}$, selectivity $s_i = \frac{\mathrm{TP}}{\mathrm{TP+FP}}$, false alarm rate $f_i = \frac{\mathrm{FP}}{\mathrm{FP+TN}}$, Matthews correlation coefficient $c_i = \frac{\mathrm{TP*TN-FP*FN}}{\sqrt{\mathrm{(TP+FP)(TP+FN)(TN+FP)(TN+FN)}}}$, and finally the overall accuracy $a_i = \frac{\mathrm{TP+TN}}{\mathrm{TP+TN+FP+FN}}$, where TP are the true positives, FN are false negatives (positives predicted by a learner as negatives), FP counts false positives (negatives predicted as positives), and TN are equal to the number of true negatives. The sensitivity for a given class l is the probability of correctly predicting an example of that class. The specificity for a class l is the probability that a positive prediction for the class is correct. The accuracy is the overall probability that prediction for class l is correct. False Alarm Rate is the probability that an example which does not belong to the class l is classified as belonging to this class. The correlation coefficient is a measure of how predictions for a class l correlate with actual training data classification. If predictions match exactly actual data, correlation coefficient is equal to *+1*. If predictions disagree with training data classification, the correlation coefficient is equal to *−1*. Zero value *0* is achieved for an average random prediction. Those parameters are calculated for all training examples, and averaged over k classes. They impact how individual learners interact with each other during meta-learning optimization phase. The quality estimators for predictor i affect its influence strength during the consensus. In large and diverse ensemble of learners the individual differences between learners can be described as random variables with a probability density $\ddot{p} = (p_i, s_i)$.
3. Meta-Learning space

   One can calculate the learning distance $d(i, j)$ between two learners i and j. The strength of coupling between two agents tends to decrease with the learning distance between them. Determination of the learning metric is a difficult problem, and the particular form of the metric and the learning distance function should be empirically determined for a given type of learning data. In the case of strongly diverse meta-learning model, individual learners are randomly connected to others without any metric structure. On the other hand, if the learners' details of internal learning algorithm are similar, then Euclidean space with Cartesian coordinate system can be introduced. In that case, the decay of learning coupling is described by a function $\frac{1}{g(d(i,j))}$, equal to constant value g for $d(i,j) < R$, and ∞ for more distant pairs. In order to test the stability of meta-learning solutions typically temperature T of the system is introduced by choosing $g(0) = \frac{1}{\beta}$, with $\beta = \frac{1}{kT}$.

4. Meta-Learning coupling

   Agents exchange their opinions for a given training example m by biasing others' responses toward their own classification outcome. This influence can be described by the total meta-learning impact I_i that ith agent is experiencing from all other learners, when classifying a training example. Within the cellular automata approach this impact is the difference between positive couplings of those agents that hold identical classification outcome, relative to negative influence of those who share the opposite state:

$$I_i = I_p\left(\sum_j \frac{-c_{ij}}{g(d(i,j))}\left(1-\sigma_i\sigma_j\right)\right) - I_s\left(\sum_j \frac{s_j+p_j}{2*g(d(i,j))}\left(1+\sigma_i\sigma_j\right)\right) \quad (1)$$

where $g(d(i,j))$ is a decreasing function of distance $d(i,j)$, and $\sigma_i\sigma_j = +1$ for $\sigma_i = \sigma_j$, or $\sigma_i\sigma_j = -1$ otherwise.

The modified Matthews correlation coefficient for two agents i and j is equal to $cc_{ij} = \frac{TP_{ij}*TN_{ij}-FP_{ij}*FN_{ij}}{\sqrt{(TP_{ij}+FP_{ij})(TP_{ij}+FN_{ij})(TN_{ij}+FP_{ij})(TN_{ij}+FN_{ij})}}$, and describes the strength of coupling between classification models of two agents. The correlation coefficient is a measure of how predictions of agent i correlate with predictions of agent j, without comparing them with given training data classification. The agreement or disagreement between learners is summarized using the contingency table, which displays the frequency distribution of the variables in a matrix format. Two binary variables are considered positively associated if most of the data falls along the diagonal cells. In contrast, two binary variables are considered negatively associated if most of the data falls off the diagonal. The symmetry between sensitivity and selectivity is assumed here, where both have the same impact on final consensus solution. The sensitivity evaluates the probability of correctly predicting a training example. The specificity is the probability that a positive prediction is correct. This selection is arbitrary and can be adjusted to specific needs of a user, for example, the sensitivity can be weighed more strongly in the model, or accuracy can be used for weighting the correct answers. Moreover, the false alarm ration can be used for weighting the negative feedback in the system, instead of correlation coefficient. Summarizing, in the present version of meta-learning procedure the persuasiveness describes how effectively the individual state of agent is propagated to neighboring agents, whereas supportiveness represents self-supportiveness of single algorithm.

The equation of dynamics for a given training example changes the individual prediction outcome σ_i' of ith individual learner into randomly selected from $k-1$ other states at the next time step, if positive value of meta-learning coupling is achieved. In the case of negative value of coupling no change is observed, and the individual prediction class for agent i is preserved. In the case of two class problem ($k = 2$), the dynamical equation is written as follows:

$$\sigma_i' = (-sign(\sigma_i I_i)) \quad (2)$$

with rescaled learning influence:

$$I_i = \sum_j \frac{-c_{ij}}{c*g(d(i,j))}\left(1-\sigma_i\sigma_j\right) - \sum_j \frac{s_j+p_j}{(s+p)*g(d(i,j))}\left(1+\sigma_i\sigma_j\right) \quad (3)$$

The states of all agents are updated in parallel until the steady state is reached. Such synchronous dynamics takes shorter time to equilibrate than serial methods, yet it can be trapped into periodic asymptotic local states with oscillations between neighboring agents. It is much faster in comparison to standard Monte Carlo methods.

5. Noise

   The randomness of the state change (phenomenological modeling of various random elements in the learning system, selection of features describing the classification model, and/or training data) is given by introducing a noise into the dynamics. In the case of two class problem, the modified equation is given as:

$$\sigma_i' = (-\mathrm{sign}(\sigma_i I_i + h_i)) \quad (4)$$

   where h_i is the learner-dependent noise. One can use white noise, or even an uniform white noise, where for all agents $h_i = h$. In the first case, h_i are random variables independent for different learners and time points, whereas in the second case h are independent for different time points. Moreover, the probability distribution of h_i can be both site- and time-independent, i.e., it can have uniform statistical properties. The uniform white noise simulates the global bias affecting all learners (like imperfections in training data), whereas site-dependent white noise describes local effects (such as prediction quality of individual learner in heterogeneous populations of machine-learning algorithms).

The system defined here is similar to previously formalized cellular automata models of opinion change in social sciences (Lewenstein et al. 1992; Plewczynski 1998). The main differences of those approaches from the previously described cellular automata models is given by the more complex, multi-class state description, and linking the quality of classification models built by each learner with its overall cognitive performance. In addition, the random strength parameters are described by the static quality estimators, therefore allowing for more complex learning behavior of the system. The impact function is also included, so learners are able to exchange their opinions for a given training example classification by the meta-learning coupling procedure. In general, the optimization goal of the meta-learning procedure is constructed here by minimizing the free energy of the system, with constrains imposed by the existence of the single solution, and that the probabilities of both answers should sum to one.

Important Scientific Research and Open Questions

The mean-field theory studies a variety of stationary states for a given dynamical system, and its intermittent behavior when the system is reaching the stationary state. The statistical mechanical model of social impact was first proposed by Latane and then extended by Lewenstein (Lewenstein et al. 1992). The impact of a group of N agents on a given learner is proportional to three factors: the "*strength*" of the members of the whole ensemble, their "*social*" distance from the individual, and their number N. These model leads to ferromagnetic and spin-glass phases, when different values of persuasiveness and supportiveness are assumed. Later, Kohring did the extension of the model to include learning (Kohring 1996). The Ising model of social impact allows for more detailed analysis of the impact of connections strengths on the final opinion clusters. The Lewenstein's class of models of cellular automata with intrinsic disorder was later extended to continuous limit by Plewczynski (Plewczynski 1998), and proved that even the model of Cartesian social space (therefore, not fully connected) and containing no learning rules, one can also observe different phases (small clusters in the sparse phase with large role of strong individuals, and high density phase with almost uniform opinion).

The balance between environment and trained model can be described similarly to social influence theory as the global parameter affecting all constructed learning models. Such methodology is directly taken from *Computational Intelligence* (CI) (Engelbrecht 2007), where each intelligent agent performs training on available input data toward classification pressure described by the set of positive and negative cases. When the query testing data is analyzed each agent predicts the query item classification by "yes"/"no" decision. The answers of all agents are then gathered and fused into the single prediction. The integration scheme allows for adaptive changes when different set of input data is presented to the system by retraining all learners. In order to differentiate members of learning ensemble from cognitive agents, we name low level combinations of several learning or clustering algorithms as *categorization units (CU)*, whereas single algorithms are described as learners.

The mean-field theoretical framework presents significant advancement over the presently available meta-learning procedures that are more heuristic. It allows for detailed studies of dynamical and emergent effects in the limit of large number of categorization units. The main problem is that actually the internal states for all used machine-learning algorithms are not changed during the course of evolution. Therefore, the bias impact only consensus phase, without changing the internal states of the multi-learner system. On the other hand, such synchronous system can be calculated much more rapidly than more complex models. The final decision outcome for the consensus system is calculated using majority rule in the stationary limit, yet the minority solutions can survive inside the majority population as the complex intermittent clusters of opposite opinion.

Cross-References

► Anticipatory Learning Mechanisms (in Autonomous Agents)
► Commonsense Reasoning (in Machine Learning)
► Gene Set Enrichment Meta-Learning Analysis
► Learning Agents and Agent-Based Modeling
► Learning Algorithms
► Learning and Evolutionary Game Theory
► Learning to Learn
► Machine Learning
► Machine Learning of Natural Language
► Metacognition and Learning
► Meta-Learning
► Metatheories of Learning
► Probability Theory in Machine Learning
► Schema-Based Architectures of Machine Learning
► Schematic Influences on Category Learning and Recognition Memory
► Social Cognitive Learning
► Social Interactions and Effects on Learning
► Social Interactions and Learning
► Social Learning
► Social Learning Theory
► Social Networks Analysis and the Learning Sciences

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Mean-Field Theory of Semiotic Landscape Formation

► Mean-Field Theory of Meta-learning

Meaning Construction

► Learning as Meaning Making

Meaning Development in Child Language: A Constructivist Approach

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Synonyms

Constructivism: sociocultural approaches; Emergentism; Interactionism

Definition

Constructivists are marked by their high attention to the construction of meaning collaboratively, and also to the interplay between the individual and the environment. In other words, according to the constructivist vision of learning, the child has a meaning potential, a semantic system that is shared between himself or herself and the significant other. It has been developed by an ongoing process, in which the others first track the child by participating in his acts of meaning, and then reinforce, extend, and modify the child's meaning system through the effects of their own responsive acts (Halliday 2003, p. 143).

Theoretical Background

It is widely accepted that meaning acquisition and meaning development is one of the critical aspects of child language. If a child is unable to say what he or she means or means what he or she says, he or she has not acquired a language, irrespective of how much he or she gains mastery over syntax and phonology (Lust 2006). On the other hand, it is a controversial issue on the time of meaning acquisition since there are some beliefs that meaning exists in the child's mind prior to language production. The purpose of this chapter is to elaborate how meaning is developed rather than when it is acquired, and then some implications for (second) language teachers and students will be revealed.

Early Approaches in Meaning Development

Meaning is not right over there to see, to grasp and to learn; rather it is constructed in a communicative event by interlocutors in an interactive way. Lust (2006) noted that during childhood the child needs to link his or her *cognitive* concepts to the *language codes* that he or she hears. In this way, *meaning construction* proceeds and does not end but develops as the child grows. So there is not a fixed meaning for every language code or concept because cognitive concepts can be changed. Historically, many theories have come into existence to explain the acquisition of *word meanings* in children, but they seem to be complementary rather than unitary. They include *semantic feature theory* (Locke 1968; Clark 1973), *prototype theory* (Anglin 1977; Rosch 1973; Rosch and Mervis 1975), *ontological constraints* (Gordon 1985), and *semantic constraints* (Markman 1994). These theories cast light on the content of mental representation of the child regarding meaning acquisition. Semantic feature theory assumes that children acquire the word meanings by gradually adding the universal binary semantic features to a concept or a lexicon. On the other hand, in the prototype theory, a particular object that fulfills the mental representation of that object stands for a prototype indicating the meaning of that object. Other relevant objects are graded around that particular prototype.

Semantic feature theory foundered as Lust (2006) argued on the basis that researchers realized that there cannot be found the binary semantic features for all the existing words and also the results of this assumption varied cross-individually and cross-culturally. Prototype theory also failed to gain support as ill-defined criterial features were used to assign the prototype. Other theories did not necessarily represent the mental representation of the child regarding word meaning. In sum, the above-mentioned approaches to word meaning are cognitive in nature and have not included the social aspect of meaning construction in their accounts.

Constructivism

Cognitive theories fall into two areas of "processing theories" and "emergentist" or "constructional approaches." Within the second group, there are some approaches known as "emergentism," "connectionism," "functionalism," and "constructivism" (Mitchell and Myles 2004). Despite the fact that cognitive theories of language learning put an emphasis on the cognition and knowledge storage to represent meaning acquisition, *constructivist* approaches are grounded in the key constructs of social interaction, mediation, zone of proximal development (ZPD), negotiation of meaning, and interaction hypothesis (IH). These constructs have been clarified as follows:

Language learning is a social event and from the constructivist view of learning as Arnold and Fonseca (2007) argue, parents provide *scaffolding* for children to acquire knowledge, to get meaning, and to develop in the process of language acquisition. In this process, scaffolding can be in terms of pauses, simplified codes, here-and-now situations, and adding information to the words. In fact, these facilitators are examples of ZPD to which Vygotsky (1978) referred. To put it another way, it has been hypothesized that even children in their early beginning of life make use of joint constructions in their acts of meaning. Some constructivist theories in first language acquisition include *Halliday*'s Learning of Meaning, V*ygotsky's* ZPD, *Tomasello*'s Psycholinguistic Model of Language Acquisition and *Clark*'s Principles of Pragmatics. Of course there are different views and perspectives which consider language acquisition a social process. From the cognitive perspective of Piaget, social interaction is given a secondary role, whereas in Vygotsky's perspective, social interaction is given a primary role. Social interaction as Vygotsky (1978) defined means that language is socially constructed and emerges out of the learner's interaction with his environment. Moreover, language is intrinsically tied to social interaction. He proposed the key construct of "*mediation*" to mean that it is a social interaction that is brought about by creating tools and functions are performed in collaboration with others. In Vygotsky's view, children are in the process of social interaction in a sociocultural

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community that is mediated by speech. Lantolf (2000) also argues that interaction is a form of mediation through which learners construct new forms and functions collaboratively.

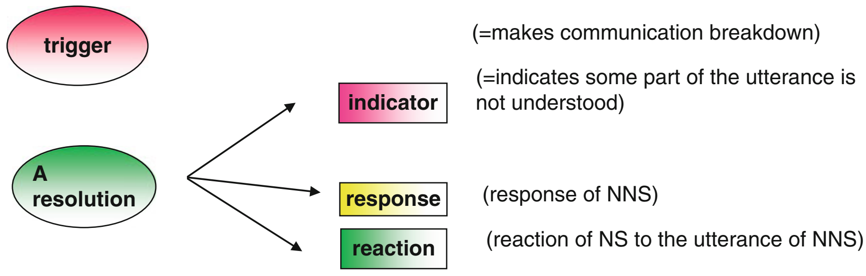
Zone of Proximal Development (ZPD) refers to the idea that learners construct meaning through socially mediated interaction and when the adults or proficient learners help the novice learner to develop language through social interaction (Fletcher and Garman 1986). This social interaction is in line with the notion of *scaffolding* proposed by Bruner; that is, when a person helps another one who cannot perform independently. Vygotsky argues that in language learning the external scaffolding includes modeling, coaching, and feedback, while internal scaffolding is when the learner is engaged in self-monitoring and reflection. *Negotiation of meaning* is another term included in the constructivist approach. From the perspective of Vygotsky, it is a kind of mediation (device) that parents employ to help the child move from "object-regulation" to "self-regulation." In the view of interactionists such as Long (1996), interaction is negotiation for meaning that facilitates acquisition, because it connects input, learner internal capacities, and output in production ways. Negotiated interaction is influential in the language development of child. Concerning L2 learners, negotiation occurs when the learner notices the discrepancy between what he or she knows about L2, and either what he or she does not know or what a native speaker knows about L2.

Interaction

Gass and Torres (2005) define interaction as exchanges in which there is some indication that an utterance has not been entirely understood. In this case, conversational exchange has the following structure (Fig. 1):

In sociocultural theory, interaction is of two kinds: "social interaction" and "private speech," or to name Vygotsky's perspective, "interpersonal interaction" and "intrapersonal interaction"; "interpersonally," when people communicate in face-to-face activity through oral or written medium, and "intrapersonally," when different modules of the mind interact to construct meaning as a response to a phenomenon (Vygotsky 1978). Interactionists argue that *interactionally modified input* can help the learner in the process of learning more effectively than *simplified input*. In this way, interlocutors collaboratively construct the meaning and reach the mutual understanding. In the process of language acquisition, the child is surrounded by both the positive and negative feedback; nonetheless, it is positive feedback that provides scaffolding for the child to help language development.

Today, with the focus on "process" in the path of language acquisition, it is believed that language has emerged through interaction and negotiation for meaning. Doughty and Long (2003) elaborate on the idea that there are two types of evidence in the environment that foster acquisition: positive and negative evidence. Gough and Hatch (1975, cited in Doughty and Long, 2003) were among the pioneers who proposed the idea that language acquisition is fostered by conversation. Earlier in this field, it was assumed that language acquisition is fostered by the modified input in the environment; that is, when the NS or proficient speakers adjust their language to the level of low-level learners to make it more comprehensible. In interactionist view, there is more than speaker modification or modified input in the form of simplification to foster language acquisition. As Doughty and Long (2003) argue, "*Simplification*" is not sufficient, but the proficient speaker should provide an opportunity to



Meaning Development in Child Language: A Constructivist Approach. Fig. 1 (From Varonis and Gass 1985, cited in Ellis 1999, p. 4) interact with another less proficient speaker to make input comprehensible. In other words "*Modified interaction*" needs to be taken into account rather than "simplification" or "premodification." During modified interaction, learners make use of the *comprehension checks*, *clarification requests* or *confirmation*, and *self-repetition* to remove the problems in interaction. Lantolf (1996, 2000) argued that SLA in the view of IH is the process that occurs in the mind of learners rather than in people-embedded activity. He further asserts that interaction is a form of mediation through which learners construct new forms and functions collaboratively.

Second Language Learning and Meaning Development Through Constructivist Approach

The constructivist perspective of language learning is applicable in the context of foreign language classes. Arnold and Fonseca (2007) propose that instead of stressing individuality, rote-learning of vocabulary and a grammar-centered approach, the teacher is suggested to put an emphasis on meaning and context that is interactionally negotiated. The constructivist approach can potentially influence the educational system in general and language learning in particular. Also it gives insight to the content and the structure of educational system. In the case of language learning, the syllabus, the methodology, and the testing process will be affected. The content of the classroom is in the direction of process-oriented rather than product-oriented approach, and the learners' needs and interests should be dealt with. Learners learn the materials while they are collaboratively involved in the act of learning and the meaning is constructed through negotiation of meaning. The pattern of teaching is not T–S, but T–S, S–T, and S–S (T=teacher; S=student). Evaluation measures the learners' creativity and amount of their participation through joint works such as project, fieldwork, and communicative acts rather than memorization. Furthermore, "testing" process has been replaced by the process of "assessment." Moreover, the format and the structure of the classroom is not in the form of a rectangle with the position of the teacher in one side facing all students; rather it is in the form of a circle (or semi-circle) in which the teacher is one member of this structure.

Moreover, language is a sign of creativity, and the ability to conform form of language to appropriate setting is one realization of this creativity. Through interaction and interpersonal activities, creative language use plays an important role as the learners engage in discussion to meet mutual understanding. If we are to claim that the language learning in our educational system is meaningful, it should be embedded in conversation. By providing technological aids, software and realia in the classroom, even traditional textbooks and exercises would be beneficial and promote acquisition. In social setting, in general, and in classroom setting, in particular, there has always been misunderstandings or problems in communication among the interlocutors. Through setting an appropriate time for "interaction," these meaningful problems would fade away and that setting, especially the classroom setting, would provide a context for growth and development of participants. It is worth saying that there should be some teacher training programs to expand teachers' vision in collaborative teaching and constructivist approaches.

Important Scientific Research and Open Questions

Although there exist many theories of language acquisition and development, some studies are needed in the area of constructivism to get to know how it is possible for the child to crack the code so easily. One issue is how "social interaction" or "negotiation for meaning" helps the child to assign different meanings to the same entity or to limit a range of meanings to the same concept. Another issue is that although there are different theories of meaning development in child language, there are still big challenges concerning the variations in this process. Individual variations such as cognitive style, personality variables, motivation, context of growth, and gender can be studied thoroughly as they strongly affect this process. So it is necessary to direct the researchers' attention to the particulars in the process of language acquisition than to the universals. The next challenging question is the nature of input. Although "input" has been already recognized to be an important factor in language acquisition, it has been recently found that the didactic nature of input is a crucial factor. In other words, premodified or simple input has given the way to the modified input. The last issue is what constitutes the mind of the child when they acquire the language. Based on the UG explanation, children's minds have been preprogrammed with syntactical rules, but in the view of constructivists or sociocultural approaches, the mind needs to be encapsulated by the syntactic, semantic, and pragmatic knowledge so the child can learn the meaning.

Cross-References

- ► Collaborative Learning
- ► Concept Learning
- ► Constructivist Learning
- ► Infant Language Learning
- ► Language Acquisition and Development
- ► Socio-Constructivist Models of Learning
- ► Vygotsky's Philosophy of Learning

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Meaning Making

► Generative Learning

Meaning Perspective

The makeup of cultural and psychological assumptions in which our past experiences are integrated and eventually transformed into new experiences. A meaning perspective is made up of a series of meaning schemes and is akin to a frame of reference.

Meaning Potentials

► Affordance and Second Language Learning

Meaning Scheme

The amalgamation of our beliefs, judgments, feelings, and concepts which all inform and influence a particular interpretation which can be shared with others.

Meaningful Learning

- ► Active Learning
- ► Constructivist Learning
- ► Experiential/Significant Learning

Meaningful Learning in Economic Games

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Synonyms

Declarative learning; Explicit learning

Definition

In economic games (strategic interactions) played repeatedly, players can engage in some combination of *strategy learning* and *meaningful learning*. Strategy learning describes the process by which players gradually learn which strategy produces the highest payoffs in a particular game. Meaningful learning describes the process by which players come to understand meaningful principles (e.g., dominance, backward-induction, strategic signaling) that are relevant not only in the current game, but in others as well. Both strategy learning and meaningful learning can contribute to improved performance (i.e., convergence toward equilibrium) in a particular game. Meaningful learning is demonstrated when improved performance in one game transfers to a superficially different but strategically similar game (i.e., a game in which the same meaningful principle applies).

Theoretical Background

There is considerable evidence in psychology that people learn in heterogeneous ways, characterized by how learning takes place, the resulting knowledge, and the ability of individuals to transfer what they learn to novel contexts.

One type of learning studied within psychology, variously referred to as "implicit," "procedural," or "unconscious" learning (Holyoak and Spellman 1993), involves unconscious processes that yield knowledge that is neither accessible to cognition nor verbalizable. A key aspect of this kind of learning is that it operates through perceptual and associative processes, rather than through cognition, and therefore fails to produce cognitive or conceptual representations of what is learned. An important consequence of the absence of such meaningful representation is that what is learned through implicit learning cannot be consciously manipulated or transferred to new domains.

The other type of learning, commonly referred to as "explicit," "declarative," or "conscious" learning (Holyoak and Spellman 1993), operates through individuals coming to obtain meaningful cognitive representations of underlying concepts, rules, and relationships. Unlike the knowledge acquired via implicit learning, the knowledge acquired via explicit learning is consciously accessible, generalizable, and verbalizable. Moreover, explicit learning involves cognition, the evaluation of hypotheses, and often results in the development of improved general problem-solving ability. Thus, a key property that distinguishes explicit from implicit learning is that the former is less context-dependent and generates knowledge that can transfer to novel situations.

Within economics, and most notably within the extensive literature on learning in strategic games, researchers have largely ignored the above distinction. Many experimental studies on games demonstrate that players do not initially play equilibrium strategies, but that repetition leads behavior to converge toward equilibrium play. Several models attempt to provide a theoretical basis for this regularity (see Camerer 2003, Chapter 6 for a review). While these models vary in the details of how learning occurs, most assume that learning operates by players engaging in an adaptive, incremental process based on observation of how well different strategies perform – either by playing those strategies, observing others playing them, or observing (foregone) outcomes produced by unselected strategies – and adjusting toward better-performing strategies. Thus, most such learning models focus on understanding how players gradually adjust their behavior toward strategies that yield the highest payoffs in a specific game, in a process best described as *strategy learning*, similar to the implicit learning discussed above. The study of learning in games, and learning in economic settings more generally, has devoted considerably less attention to understanding the alternative process, *meaningful learning*, whereby individuals come to understand meaningful principles that can be transferred across games.

Important Scientific Research and Open Questions

The study of learning in games is beginning to devote attention to the conditions that stimulate meaningful learning. Given the correspondence between what psychologists call implicit learning and what economists call strategy learning, manipulations commonly employed in psychology experiments to inhibit implicit learning and stimulate explicit learning could serve an analogous function in strategic interactions and could facilitate meaningful learning.

For example, one such manipulation involves the amount of feedback participants receive about task performance. Counterintuitively, psychologists have often found that deeper and more meaningful learning is more likely when people receive minimal or delayed feedback than under full and immediate feedback (e.g., Goodman 1998).

Rick and Weber (2010) examined whether such manipulations would have analogous effects on meaningful learning in repeated games. Specifically, Rick and Weber manipulated whether or not subjects received round-by-round outcome feedback in a repeated *p*-beauty contest.

In a p-beauty contest, *N* players each choose a number (s_i) in a given range. The average of the *N* numbers is then multiplied by a constant (p) to obtain a target number. The player whose choice is the smallest absolute distance from the target number wins a fixed prize. Rick and Weber used an "Infinite Threshold" (IT) version of the game ($p = 0.7$, $s_i \in [0, \ 100]$) and a "Finite Threshold" (FT) version of the game ($p = 1.3$, $s_i \in [100, \ 200]$). Iterated deletion of dominated strategies selects unique symmetric equilibria in these two games. In the IT game, infinite iterations of multiplying 0.7 times the upper bound of 100 yields the Nash equilibrium of $s_i^* = 0$. In the FT game, three iterations of multiplying 1.3 times the lower bound of 100 yields the Nash equilibrium of $s_i^* = 200$. Thus, both games are solvable by iterated deletion of dominated strategies.

Groups of subjects initially played ten rounds of one version (Part 1), and then ten rounds of the other version (Part 2). Rick and Weber (2010) found that subjects who played Part 1 without feedback chose strategies significantly closer to equilibrium in Part 2 than did subjects who played Part 1 with consistent feedback. That is, playing the first game without feedback yielded significantly greater learning transfer. The results suggest that withholding feedback encouraged subjects to think more deeply about the game, facilitating their acquisition of a meaningful principle (i.e., iterated dominance). Rick and Weber (2010) further examined this interpretation in a subsequent experiment that crossed a feedback manipulation with a self-explanation manipulation (whereby subjects either did or did not explain why they chose what they chose – a method commonly employed in psychology to stimulate deeper thinking). Subjects initially played ten rounds of the FT game under one of these four conditions (Part 1), and then one round of the IT game (Part 2). Rick and Weber found that self-explanation enhanced meaningful learning (as measured by distance from equilibrium in Part 2) when feedback was provided, but provided no additional benefits when feedback was withheld. Given that both interventions (withholding feedback and prompting self-explanation) have similar and substitutable effects, withholding feedback appears to stimulate the type of deep thinking and meaningful learning that occurs when prompted to self-explain.

In addition to withholding feedback and requiring verbalization, several other interventions found in psychological research to enhance deeper thinking (e.g., inducing positive affect; Isen et al. 1987) might also stimulate meaningful learning in economic settings. In related research on behavior in games, Cooper and Kagel (2003) found that either team play or the use of meaningful context in a game involving strategic signaling, in which a first-mover attempts to signal her willingness to compete through a costly action to a second-moving player, yielded significantly greater transfer of learning to a subsequent similar signaling game. The efficacy of additional interventions warrants subsequent research. Additionally, future research should strive to further develop economic models that account for both strategy learning and meaningful learning.

Cross-References

▶ Complex Problem Solving
▶ Feedback and Learning
▶ Feedback Strategies
▶ Strategic Learning

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Meaningful Verbal Learning

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Synonyms

Concept learning; Reception learning

Definition

The theoretical approach of meaningful verbal learning was developed by Ausubel in the 1960s as a contrast to rote learning. Indeed, Ausubel made the very important distinction between *rote learning* and *meaningful learning*. Meaningful verbal learning corresponds to a large extent to concept learning. It involves the functional internalization of the verbal material presented to learners and occurs through progressive differentiation and integrative reconciliation. The basic assumption is that concepts are organized hierarchically in the mind and that the most inclusive concepts at the apex subsume progressively less inclusive and more differentiated subconcepts.

Theoretical Background

Ausubel was largely influenced by Piaget's epistemology and constructivist evolutionism. Together with Bruner he contributed much to the foundation of cognitive learning theory. In contrast to the neo-behaviorist views on learning, Ausubel focused on meaningful verbal learning and related conceptions of instruction.

In accordance with Piaget, the assimilation or *subsumption* of new experiences into existing structures is at the core of Ausubel's theory of meaningful verbal learning. As learning proceeds, the learner organizes the content of a particular topic into a hierarchy of concepts, with inclusive concepts at the apex and progressively less inclusive but more differentiated concepts at lower levels of the hierarchy.

▸ Children progress through a regular sequence of stages in their transition from dependence upon concrete material to the ability to apprehend the meaning of abstract propositions presented symbolically . . . while the young child is manifestly dependent upon concrete experience in his learning . . . beginning in the junior high-school period, students can acquire most new concepts and can learn most new propositions by *directly* grasping relationships between abstractions . . . In large measure this development reflects the availability of an adequate body of higher-order abstractions and transactional terms. (Ausubel and Robinson 1969, p. 90)

Based on this developmental perspective, the major characteristics of meaningful verbal learning can be summarized as follows: (1) The situations in which learning takes place consist exclusively of learning tasks in the form of verbal material. (2) The main task of learning is to understand the material, i.e., to impart meaning to the material by assimilating the statements into an enduring cognitive structure. (3) The cognitive structure must also provide suitable links (so-called anchors) to enable the learner to put the pieces of information to be assimilated in relation to one another. Ausubel comprehends assimilation as a process of *subsumption*, which means that new material is incorporated into existing cognitive structures. Only when an individual encounters completely new and unfamiliar material does rote learning, as opposed to meaningful learning, take place. This rote learning may eventually contribute to the construction of a new cognitive structure which can later be used in meaningful learning. When information is assimilated or subsumed into the learner's cognitive structure it is organized hierarchically. New material can be subsumed in different ways, such as through progressive differentiation and integrative reconciliation, but no meaningful learning takes place unless there is a stable cognitive structure which can provide a framework for relating the new learning to the previous information or concepts in the individual's cognitive structure. Accordingly, Novak and Cañas (2008) distinguish three conditions for meaningful (verbal) learning:

1. The material to be learned must be conceptually clear and presented with language and examples that can be related to the learner's prior knowledge.
2. The learner must possess relevant prior knowledge. Novak and Cañas argue that this condition can be met after age 3 for virtually any subject matter domain.
3. The learner must choose to learn meaningfully rather than simply memorizing facts, definitions,

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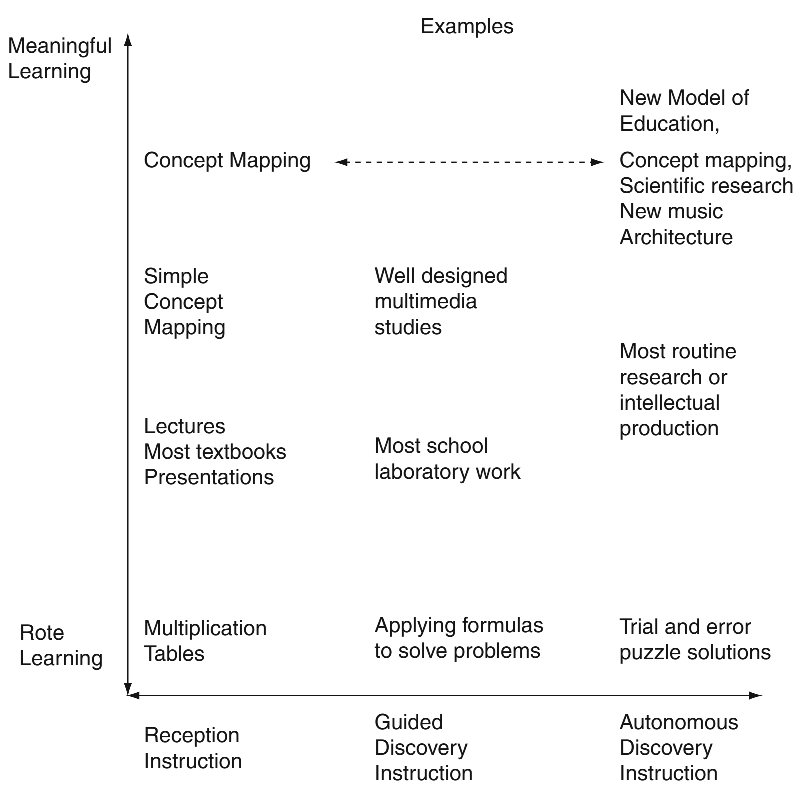
statements, or procedures. The one condition over which the teacher or mentor has only indirect control is the motivation of students to choose to learn by attempting to incorporate new meanings into their prior knowledge.

According to Ausubel, there are two forms of meaningful verbal learning: *progressive differentiation* and *integrative reconciliation*. By means of progressive differentiation learners increase the degree of elaboration of a concept as they increase their understanding about it (Ausubel 2000), whereas the process of integrative reconciliation allows the learner to discern relations between concepts which are not initially categorized. There are two types of integrative reconciliation learning: superordinate integrative reconciliation and combinatorial learning. *Superordinate integrative reconciliation* occurs when the learner identifies a more inclusive concept, whereas *combinatorial learning* happens when the learner discerns the need for relating concepts without having a more inclusive concept at hand (for more details, see in the entry on "► Assimilation Theory of Learning").

Another important ingredient of Ausubel's theory of meaningful verbal learning is the concept of advance organizers. An advance organizer is a mental tool or a learning aid for helping students to integrate new information into their existing knowledge. It is a device for activating the relevant conceptual patterns, thus allowing new information to be more readily assimilated into the learner's existing cognitive structures. (for more details, see the entry on ► Advance Organizers).

Important Scientific Research and Open Questions

Novak and Cañas (2008) argue that people often confuse rote learning and meaningful (verbal) learning with instructional approaches that vary on



Meaningful Verbal Learning. Fig. 1 The rote-meaningful learning continuum is not the same as the reception discovery instructional continuum (Novak and Cañas 2008) a continuum from expository teaching (and a direct presentation of relevant information) to discovery learning, which involves having the learners discover regularities and procedures for accomplishing the learning tasks by themselves. However, both expository and discovery teaching methods can result in rote and/or meaningful learning depending on the motivational and cognitive dispositions of the learners and how well organized the material to be learned is. Therefore, Novak and Cañas conclude that the rote-meaningful learning continuum is not the same as the reception discovery instructional continuum. Their argumentation is summarized in Fig. 1. Furthermore, they point out that so-called inquiry studies do not guarantee meaningful learning but rather "the reality is that unless students possess at least a rudimentary *conceptual* understanding of the phenomenon they are investigating, the activity may lead to little or no gain in their relevant knowledge and may be little more than busy work" (Novak and Cañas 2008).

Since Ausubel's introduction of the idea of meaningful verbal learning in the 1960s, many empirical studies have focused on the effectiveness of advance organizers (for more details, see the entry on "► Advance Organizers"). Another major field of research resulted in the application of concept maps as tools to help students organize verbal information (Novak 1998). Concept mapping can be considered the most practical application of Ausubel's theory of meaningful verbal learning developed to date. Concept mapping presupposes a process of externalizing the mental connections and association patterns that a student makes on knowledge learned in the form of drawings and diagrams. However, concept maps are not only applicable as learning tools but also as assessment tools (see Ifenthaler et al. 2010).

Cross-References

- ► Assimilation Theory of Learning
- ► Ausubel, David P.
- ► Concept Learning
- ► Concept Maps
- ► Meaning Development in Child Language

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Meaninglessness

► Boredom in Learning

Means/Ends Behavior

► Instrumental Behavior, Problem-Solving, and Tool Use in Nonhuman Animals

Measurement of Change in Learning

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Synonyms

Learning tests; Measurement of growth; Measurement of variability; Statistical models for longitudinal data

Definition

Measurement of change refers to the assessment of variability on the one hand, and to the assessment of change in a narrower sense on the other hand. Variability is characterized by fluctuations that are of short duration and reversible (e.g., variability of mood states). In contrast, change in the narrower sense is persistent and often irreversible (e.g., development of language skills). The measurement of variability is described by Eid and Luhmann (this volume). This entry focuses on measurement of change in the narrower sense.

Change can be caused by natural processes such as maturation or by interventions such as trainings or the presentation of specific items and tasks (e.g., learning during the test completion). Change that is caused by natural processes is typically analyzed with growth curve models. Change that is caused by interventions can be analyzed with intervention analysis. Finally, change that occurs during a test session can be analyzed with learning tests. Measurement of change can further be classified into whether the change is assumed to be quantitative (i.e., continuous) or qualitative (i.e., discontinuous, categorical, changing from one stage to the next).

Theoretical Background

Modeling Growth and Decline

Growth is an increase and decline is a decrease of a trait or ability over time. Both types of change can be modeled with growth curve models. Growth curve models for continuous variables (i.e., *quantitative change*) are special variants of regression models where the trait or ability is the dependent variable Y and time (or age) is the predictor:

$$y_{ti} = \pi_{0i} + \pi_{1i} \cdot TIME_{ti} + e_{ti}$$

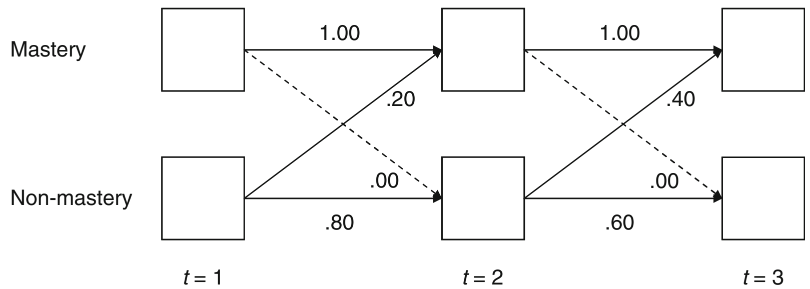
where y_{ti} is the observed value on the outcome variable Y for individual i at time t, $TIME_{ti}$ is the exact time point where this value was observed, π_{0i} is the intercept reflecting the predicted value of Y for individual i at $TIME = 0$, π_{1i} is the slope reflecting the predicted change in the dependent variable Y for individual i during one time unit, and e_{ti} is the residual reflecting the deviation of the predicted and the observed value. Time can be scaled in any unit (e.g., minutes, weeks, or years), but it should reflect actual time, not just the enumerated time points in a study. To ensure that the intercept can be interpreted appropriately, at least one time point should be coded with zero. In many cases, the zero time point (or reference time point) is the very first time point in the study, but in other cases, later time points might be of more interest. The slope reflects the predicted rate of growth or decline of the dependent variable during one time unit, for instance, during one week.

For each person, an individual growth curve is estimated. These growth curves are then aggregated so that the average intercept and the average slope can be determined, that is, the average predicted value of the dependent variable at time = 0 and the average rate of change during one time unit. In addition, it is possible to examine the variance of the individual intercepts and slopes. The variance of the intercepts reflects individual differences at time = 0, and the variance of the slopes reflects individual differences in the rate of change.

A growth model that contains only the time variable as predictor is an unconditional growth model. This model can be extended to include additional time-varying and time-constant variables in order to explain individual differences in the intercept and individual differences in the rate of change, or in order to model nonlinear change. Growth curves can be modeled as multilevel models (manifest growth curve models; Singer and Willett 2003) or as structural equation models that allow a more appropriate control of the measurement error (latent growth curve models; Bollen and Curran 2006).

In models for *qualitative change*, it is assumed that the dependent variable is categorical. Each category represents a stage, for instance, a specific learning stage or a specific competence level. In learning research, these categorical variables are typically dichotomous (e.g., mastering of certain skill or not), but it is also possible to analyze variables with three or more categories.

Qualitative change can be modeled appropriately with Markov Chain models (Kaplan 2008; Langeheine and Van de Pol 2002). In these models, the current state on a categorical variable is predicted by its state at the previous measurement occasion. Figure 1 depicts a Markov Chain model for a dichotomous variable (non-mastery vs mastery of a skill) and three measurement occasions. The probability to move from one category to another is represented in the transition probabilities. In classic Markov Chain models, the transition probabilities are assumed to be constant across all waves (stationarity). In learning research, however, this strict assumption is often not met. For instance, the probability of moving from Piaget's



Measurement of Change in Learning. Fig. 1 A Markov Chain model for a dichotomous variable measured at three occasions. The transition probabilities from non-mastery to mastery vary between different measurement occasions. The transition probabilities from mastery to non-mastery are fixed to zero and depicted with a *dashed arrow*

preoperational stage to the concrete-cognitive stage is higher at the age of 4 than at the age of 1 (Piaget 1971). Therefore, non-stationary Markov models that allow for varying transition probabilities across measurement occasions are usually more appropriate. This is illustrated in Fig. 1 where the probability to move from non-mastery to mastery is lower between measurement occasions 1 and 2 than between measurement occasions 2 and 3. Another feature of classic Markov Chain models is that transitions in all directions are allowed. For instance, it is possible to move from category 1 to category 2 and again back to category 1. This transition pattern can be restricted to test specific hypotheses. For example, it could be assumed that once a specific skill is acquired, it cannot be lost again: It should be possible to move from non-mastery to mastery, but not from mastery back to non-mastery. This assumption can be considered in the Markov Chain model by setting the respective transition probabilities to zero (see Fig. 1).

Markov Chain models can be extended to latent Markov Chain models or latent transition models (Kaplan 2008; Langeheine and Van de Pol 2002). In these models, the latent categorical variable is measured with multiple indicators to control for measurement error. The transition probabilities then refer to the probability of moving from one latent category to another. As the measurement of skills and abilities is almost always impaired by measurement error, latent Markov Chain models are most adequate to study categorical change in learning.

Intervention Analysis

To analyze the influence of an intervention, individuals have to be repeatedly assessed before and after the intervention (Eid and Hoffmann 1998). The natural change processes occurring within the pre-intervention period and the post-intervention period can be modeled in separate change models. Changes that do not occur naturally but are caused by the intervention can then be assessed by comparing the model parameters of the pre-intervention period with the model parameters of the post-intervention period. For example, interventions can change the general level of a trait or ability as well as its rate of growth or decline over time.

Learning Tests

The goal of learning tests is to assess (a) the general ability level and (b) the learning ability of the tested person (Klauer and Sydow 2001). These two constructs are relatively independent. In learning tests, the participants answer a number of ability-related items and receive immediate feedback for each item before they proceed to the next one. Thus, learning takes place *during* the test completion.

To analyze these types of tests, dynamic item response models have been proposed (e.g., Klauer and Sydow 2001). In regular item response models, the conditional probability to solve an item is a function of a person parameter (ability level) and an item parameter (item difficulty). To analyze learning tests, a second person parameter reflecting learning ability is added to the model. This learning ability parameter has an increasing influence on the probability to solve an item. That means that this parameter has no influence on the solution of the first item but a high influence on the solution of the last item. The learning ability parameter can then be used in further analyses.

Important Scientific Research and Open Questions

The statistical models presented in this entry provide powerful tools to analyze multiple complex questions simultaneously. Growth curve models assessing quantitative change are used increasingly in learning research, for instance, to analyze trajectories in academic achievement (Johnson et al. 2006) or language acquisition (Rice and Wexler 1998). In contrast, the potential of Markov Chain models and dynamic learning tests is largely untapped in the field. New software developments are currently making these methods more accessible, giving researchers the possibilities to examine new and exciting questions on change in learning.

Cross-References

- ► Longitudinal Learning Research
- ► Mathematical Models/Theories of Learning
- ► Models of Measurement of Persons in Situations
- ► Piaget's Learning Theory
- ► Stochastic Models of Learning

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Measurement of Creativity

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Synonyms

Creativity test

Definition

Creativity involves the production of new artifacts that previously did not exist and which are appreciated by other people because of their practical, intellectual, or esthetic value (Sternberg 1999). These artifacts may be of cognitive, physical, or cultural form. In order to measure the extent of people's creativity two main approaches can be followed: first, by analyzing documents and artifacts produced in the past; and second, by asking people to do something (such as answering questions or carrying out tasks) in the presence of an evaluator.

As far as the first approach is concerned, biographies or autobiographies of eminent individuals (who are usually deemed to be creative people) are taken into account. Another possibility is to ask experts to judge a piece of work which is evaluated as creative; alternatively an attempt can be made to reconstruct the creative process by analyzing the sketches and the preliminary versions which preceded the production of a creative artifact. Finally, it is possible to check the success of a creative work by recording appropriate indicators of its public acceptance and appreciation (such as the number of quotations).

In the second approach, both self-report and performance measures can be recorded. Self-report measures include interviews, questionnaires, and check-lists; performance measures consist of tests. Interviews are carried out to assess the qualitative aspects of the creative experience. Questionnaires are often employed to identify habits, beliefs, and people's conceptions related to creativity. People are asked to endorse check-lists usually to draw their personality profile. Tests provide evaluators with an objective measure of the ability to process stimuli in creative ways.

Theoretical Background

Procedures devised to measure skills and traits associated with creativity are often inspired by theories concerning creativity or are grounded in assumptions concerning the basis of creativity.

A distinction which may be useful to classify measures of creativity makes reference to tenets about the process of creative thinking. There are two important perspectives to consider. On the one hand it is believed that a creative outcome is reached by a search process which consists in a sequence of trials and errors or in a progressive adaptation. In this perspective it is important to assess if a person can learn from mistakes and take advantage from the falsification of his/her conjectures or attempts by modifying them properly. On the other hand it is believed that creative findings emerge as a consequence of insight-like experiences. In this perspective a creative person should be able to incorporate implicit hints and recognize sudden illuminations, sometimes occurring as a result of an incubation process.

Another taxonomy which can be adopted is based on the mental operations involved in creativity. To summarize, three main theoretical perspectives, which stress the role of different core mechanisms, can be identified. In the first perspective it is assumed that creativity consists (above all) in *widening* the mental framework. Accordingly, it is relevant to assess an individual's ability to keep an open mind, that is, to be aware of the great number of elements that can be caught in a given situation, to recognize not obvious meanings, to discover hidden aspects, to overcome apparent constraints, and to generate numerous and different ideas. In the second perspective, creativity is mainly thought of as being a matter of *connecting*. This refers to the capacity to establish reciprocal relationships among different elements, to draw analogies between remote things, to combine ideas in odd ways, and to synthesize the multiplicity of disparate elements into an overall structure. In the third perspective it is claimed that the core of creativity is *restructuring*. Creative skills include the capacity to change a point of view, to see things by inverting the relationships between their elements, to ask original questions, to imagine what would happen if alternative conditions occurred.

Important Scientific Research and Open Questions

Data derived from biographical records or by analyzing artifacts can be useful to assess if and how much an individual is prone to follow a creative process, that is, to revise his/her mental schemata as a consequence of his/her errors and to adapt such schemata to the suggestions coming from experience by generating different hypotheses or trying different approaches, or, on the contrary, to experience insights (Gardner 1993). The reconstruction of the creative process on these grounds was initiated by Francis Galton (*Hereditary genius*, 1869) and developed by many others in the first part of the twentieth century. For instance, Cesare Lombroso (see Antonietti and Cornoldi 2006) maintained that creative people differed from other people in that they saw things in a different manner, associated ideas usually considered separate, detected hidden relations between disparate thoughts, and, as a result, could generate new products. Lombroso claimed that creativity is close to insanity, since a series of features are shared both by creative persons and by those who are insane. By analyzing biographical data of eminent scientists, mathematicians, inventors, novelists, poets, painters, sculptors, philosophers, historians, economists, politicians, army leaders, and so on, he provided a list of these deficits. They included biological characteristics (low stature, thinness, anomalous shape of the skull), mental disorders (compulsive ideation, mania, hallucinations, delirium, amnesia, epilepsy) and deviant behaviors (alcoholism, vagabondage, suicide), special psychological features (hypersensitivity, left-handedness, intellectual precocity, somnambulism, vivid dreams, odd calligraphy), personality traits (melancholia, being afraid, ambiguity, tendency to share prejudices and stereotypes), social tendencies (being misunderstood, being refused by the contemporary environment, difficulty in accepting other people's ideas; tendency to remain unmarried), and moral traits (perversity, arrogance). Afterward this kind of approach was applied in a more rigorous way, among others, by Howard Gruber (*Darwin on man: A psychological study of scientific creativity*, 1974), who analyzed thoroughly the personal notes of the father of the evolutionary theory with an attempt to highlight the microgenesis of creative ideas by reconstructing the phases through which the author of the *Origin of species* modified his conjectures. Recently, Dean Keith Simonton (*Scientific genius*, 1988) devised a historiometric approach based on the computation of the connections between a creative product and the personal and environmental crucial variables which favored the emergence of such product (for instance, the age of its author).

Whereas the above-mentioned approaches, as well as self-report data, are particularly useful to assess the qualitative aspects of the creative process, psychometric measures are useful to test the quantitative aspects, mainly the ability to apply the mental operations (widening, combining, restructuring) assumed to be the core mechanism of creativity. The seminal work by Guilford (1950) – who proposed the distinction between convergent (non creative) and divergent (creative) thinking – inspired the construction of a series of tasks which should structurally differ from those usually employed to measure intellectual proficiency. *Convergent* thinking is activated when we have to face a problem that has only one solution, which is achieved thanks to the application of rules or thanks to past experience and by reasoning within the framework in which the problem is presented. Traditional IQ tests are relevant examples of measures of convergent thinking. In contrast, *divergent* thinking is activated when we face a situation that has multiple possible solutions, which are not reached through rules or previously learned principles and notions but are inspired by a novel approach, often requiring to assume a different conceptual framework. This is the case of creativity.

Tasks usually employed to measure creative thinking abilities ask respondents, for instance, to list as many objects as possible having a given feature, to find all possible uses of an object, to give several interpretations of a drawing, to invent a story about a given picture, to imagine the consequences of an event, to solve unusual practical problems, to complete given pictures, to write as many sentences as possible composed of three words with the same given initial, to invent symbols to denote a given concept, and to look for possible titles relevant to a given story. These tasks are aimed at measuring the features of ideational productivity and are based on the assumption that creative thinking involves a set of processes such as the free production of ideas generated by a starting stimulus; the search for correspondences, similarities, and shared elements among disparate elements; and the shift in view from which a given situation may be interpreted. Such tasks were useful to support the notion that creativity involves divergent thinking factors, which are not implied in intelligence, and to assess the possible role of gender, age, order of birth, and number of siblings – as well as of education, cultural environment, social values, and norms – in modulating individuals' creativity.

Currently the most frequently employed psychometric tool to assess creativity skills is the *Torrance Test of Creative Thinking* (TTCT) (Torrance 1974), which includes some tasks originally devised by Wallach and Kogan (1965) to measure creativity in children. To give an example, in a TTCT subtest respondents are presented a sheet reporting a series of couples of parallel lines and are asked to draw as many figures as possible, each different from the other ones, by completing the given lines and to tell a story which can connect all the drawings. A *fluidity* score is computed by counting the number of pictures produced. The *flexibility* score corresponds to the number of different categories the pictures belong to. The *originality* score is given by the number of pictures which are seldom produced in the normative sample. Finally, an *elaboration* scores is computed by judging to what extent the pictures are coherently organized within the story. Nowadays, but less used, is the *Remote Association Test* (RAT) (Mednick and Mednick 1967), which was often administered in the past. RAT requires a subject to complete a series of three words with a fourth word which can be associated to each of the three given terms. Some tests are available in two parallel forms, useful for test–retest studies.

All the tasks mentioned above are aimed at measuring "general creativity" without making reference to the features of the domain where creativity should emerge. In contrast, in everyday life, as well as in educational settings, individuals are asked to be creative in specific contexts. Consistent with this idea, in recent years contextualized measures of creativity have been devised so to allow evaluators to check whether an individual is able to generate creative ideas within a specific domain (Diakidoy and Spanoudis 2002). For instance, tests to assess creativity in music, in painting, in writing, and so on have been constructed.

Cross-References

► Analogy/Analogies
► Associationism

► Creativity and Learning Resources
► Divergent Thinking and Learning
► Nature of Creativity

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Measurement of Growth

► Measurement of Change in Learning

Measurement of Student Engagement in Learning

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Synonyms

Effort; Involvement; Learning; Motivation; Participation; Retention

Definition

► Student engagement refers to people's interaction with activities and conditions that lead to learning and development. The concept applies to learning in general but is typically used in formal educational contexts. Measuring student engagement involves capturing insights on what students are doing and their intrinsic involvement with learning, the extent to which people are making use of available resources, and the extent to which teachers and institutions are supporting learning. Empirical insights on student engagement provide a means for engaging teachers and institutions with core educational business, a structure for framing conversations about quality, and a stimulus for guiding new thinking about good practice.

Theoretical Background

Conceptually, student engagement is grounded directly in theories of how people learn. It builds directly on the epistemologies of Socrates, Kant, and Kierkegaard which see individual agency and knowledge construction as the essential of learning. It springs directly from neuroscientific theories of how neurons interact, cognitive theories of attention and memory, and understandings of motivation and agency. The concept provides a bridge between learning and what students, teachers, institutions, and systems actually do.

As these remarks suggest, student engagement tends to be interpreted as a constructivist epistemologically. Learning is seen to be a process of individuals actively building knowledge. From the perspective of Dewey and Piaget, two formative theorists, this involves both the formation of new structures and the incorporation of new experiences into existing frames. The ► quality of effort (Pace 1979) or ► individual involvement (Astin 1979) invested by learners underpins both of these processes. This has implications for measurement, which must somehow tap into the behavior, cognition, and emotion that underpins learning.

Individual involvement is necessary but rarely sufficient for learning. Learning is a joint proposition. In keeping with Piaget and related research, contemporary perspectives put much emphasis on environment and instruction. It is important, in particular, that learning environments support and stimulate inquiry, and that teachers set expectations and tasks that facilitate exploration and knowledge creation. Working collaboratively with other learners is particularly fruitful as a means of helping learners to test uncertainties and insights within what Vygotsky termed the *zone of proximal development*.

Contemporary perspectives emphasize the amount of time and effort students put into educationally purposeful activities, and the support and encouragement provided by institutions and teachers. Hence, the term student engagement is read as an umbrella term that encompasses a number of different student and institutional behaviors which have been shown to positively influence student outcomes. This broad conceptualization of the phenomenon (see Chickering and Gamson 1987; Ewell and Jones 1996; Kuh 2004; Coates 2006) embraces setting academically challenging expectations, participating in active forms of learning, learning collaboratively, interacting with teachers, providing environmental support, giving prompt feedback on performance, participating in developmentally enriching activities, spending time studying, and valuing people's unique talents and ways of learning. This is a broad scope, but it is bounded by the requirement that activities and conditions are linked with effective educational practices and hence outcomes.

These phenomena can be measured in myriad ways. Direct (i.e., observation or interview) or indirect (i.e., video recording or tracking online interactions) observation yields large quantities of very textured data, but is essentially limited in the coverage it can provide and can be resource demanding. Rather than observe students, therefore, one compromise is to ask students to record their learning experiences in time diaries which can then be collated and analyzed. While this yields rich data, it places additional burden on respondents, and requires confidence in the reliability of self observation and report. Even greater confidence in learner perceptions is required to underpin the most common means of measuring student engagement – questionnaire. Criterion validity studies have shown that learner self reports have suitable reliability for aggregated analyses, however, which combines with the efficiency and scalability of questionnaire methods to sustain their popularity in the field. Tests are rarely used to measure student engagement as many facets are not amenable to objective assessment.

But as the above definitional remarks portend, while students are the *unit of analysis* student engagement is about teachers and institutions as well. Hence, advanced approaches to measurement not only collect data from and about learners, but triangulate this with information from teaching and support staff. Collecting such information is complex and can involve interviews or surveys, or observation, and document reviews. Typically, however, such information is sourced to supplement rather than supplant data collected from students. As with the collection of data from learners, the measurement process can itself be a particularly effective means of engaging people in learning.

Important Scientific Research and Open Questions

Educational measurement is a relatively young science, and, as in many other areas, uncertainties exist with regard to the phenomenon of student engagement. Current debate circulates, among other topics, around definitional matters, measurement strategies, validating assessment approaches, and using evidence to drive change.

Securing an enduring yet relevant definition of student engagement is one of the greatest outstanding challenges. Variations exist as a result of the need for definitions to follow changing educational contexts and practices. Yet as the science of learning advances, it may be possible to develop more rigorous definitions that link the psychology of learning with educational practice. Re-specification of the phenomenon will shape the nature and approach to measurement.

The questionnaire, as noted above, has proven to be the most common means of collecting data on people's involvement in learning, particularly in higher education where the concept has been most thoroughly explored and applied – undoubtedly due to difficulties associated with defining and measuring learning outcomes. Yet the limitations of questionnaire methods are well known, raising questions about whether and how more reliable forms of measurement may be implemented.

This leads to the importance of further validating conceptual perspectives of student engagement – ensuring they embrace activities and conditions that are linked with effective educational practice. Many empirical and meta-analytical studies have been conducted and used to improve measurement instruments and approaches, yet current measures still tend to explain relatively small amounts of variation in educational outcomes, prompting questions about what other phenomena may be measured. Making matters more complex, evidence also exists that the effects of student engagement are conditional, interacting in complex ways with individual background and educational contexts.

Perhaps the most important focus for future research is finding effective ways to ► convert insights on student engagement into productive educational change. Researching student engagement focuses measurement on core facets of learning which prompts questions about improvement. The significance of the phenomenon shapes aspirations for change, but more research on change management is required to drive effective improvement.

Cross-References

- ► Academic Motivation
- ► Active Learning
- ► Activity Theories of Learning
- ► Affective Dimensions of Learning
- ► Assessment in Learning
- ► Assessment of Academic Motivation
- ► Collaborative Learning
- ► Engagement in Learning
- ► Evaluation of Student Progress in Learning
- ► Social Interaction Dynamics in Supporting Learning
- ► Styles of Engagement in Learning

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Measurement of Variability

► Measurement of Change in Learning

Measurement of Working Memory Load

► Cognitive Load Measurement

Measures of Association

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Synonyms

Co-occurrence

Definition

Measures of ► association capture the properties of external observations of the processes of ► experience. For empirical reasons, they rely on externalizations, e.g., words and other specific behavior, and thus make use of the speed and likelihood of an associative response following either a given sensation or a previously externalized idea as antecedent. The goal of the Association Measures (AM) is to determine either general and specific abilities for association by determining the speed of subsequent associations or the likelihood of the occurrence of concrete associations that come up within a learner who is confronted with a given learning environment or content. AM thus also measure how prior knowledge emerges within a learner dealing with a task, training, or presentation of ideas.

Theoretical Background

Aristotle (B.C. 384–322) laid the foundation for a general theory of association between mental states. He was interested in the thought that an idea or memory image will systematically follow another. Locke (1690) first stated a theoretical framework for the "association of ideas." Plato already provided the strong and inseparable connection between association and learning (by means of recollection) in the *Phaedo* (73–74):

► And yet what is the feeling of lovers when they recognize a lyre, or a garment, or anything else which the beloved has been in the habit of using? Do not they, from knowing the lyre, form in the mind's eye an image of the youth to whom the lyre belongs? And this is recollection. In like manner any one who sees Simmias may remember Cebes; and there are endless examples of the same thing. [. . .] and may you not also from seeing the picture of a horse or a lyre remember a man? [. . .] and from the picture of Simmias, you may be led to remember Cebes [. . .] or you may also

> be led to the recollection of Simmias himself? [. . .] And in all these cases, the recollection may be derived from things either like or unlike? [. . .] And when the recollection is derived from like things, then another consideration is sure to arise, which is - whether the likeness in any degree falls short or not of that which is recollected?

Through contiguity and similarity, the act of recollection is made possible. Through the end of the nineteenth century and the first half of the twentieth century, ▶ Association Psychology dedicated large efforts internationally to the exploration of association and its measurement by using behavioral and structuralist approaches.

While the mental states may refer to each other in a more or less organized manner, the measurement of associations works only on a behavioral level, i.e., if the learner shows behavior in the form of externalizations. Like with the empirical access to all cognitive constructs, this comes with a methodological precaution: In the end, neither the properties of the associations themselves are assessed nor measured but rather their external derivates. The question when measuring association always is: how closely related are two or more mental entities to each other? The main strategies to achieve this goal and to answer this kind of question are ▶ priming experiments, word associations, picture associations, speed of ▶ recognitions (which may be seen as a subcategory of priming experiments), and knowledge reconstruction strategies. The latter does not exist as a standardized term but is used as a stand-in for many instruments that use the explicit construction of a subject to determine association (among them are concept mapping techniques).

The direct ▶ expectation, similarity, or contiguity is induced as faster reaction by subjects on a given antecedent or stimulus (*positive priming*) while in contrast the lack of such an implicit expectation results in a slower reaction (*negative priming*). Priming occurs due to the recognition of similar forms (*perceptual priming*) or similar meaning (*conceptual priming*). The faster the recognition and the reaction are, the closer the things are considered to be associated. Effects of priming differences can be stable down to a level of a few milliseconds, even in language processing. *Associative priming* is also used to determine semantic association between words that do not necessarily have a similar meaning but are connected by frequent co-occurence (e.g., "fire and water" or "fire and alarm"). Free word associations use a similar principle where a subject orally responds to a given stimulus word with the first word that comes into his or her mind. The frequencies of large samples were used as a corpus to determine general word associatedness (e.g., with the Kent-Rosanoff test). The resulting lists exist for large groups and can either be used to contrast association of specific groups to the population or to determine suitable words for texts and headlines if specific associations are intended to be raised in clients or customers. In other association tests a given set of words are grouped or arranged otherwise by the subjects to determine either their speed of association, their congruency to a norm group, or their creativity in the arrangement. Response times or number of associations within a given time are another way to measure association. Some of the time-dependent tests aim at memory performance while others focus on creativity, e.g., the more words a subject associates within a given time to a given initial word, the higher is the considered creativity. Of course, for a construct like creativity association measures can only be one part of the whole measurement. Within ▶ Prototype Theory (PT) (Rosch 1973), word associations (response times, priming and exemplars) are used to determine best exemplars for a category and word distances within categories. The tests that come along with PT usually ask for a list of exemplars of a given category (e.g., birds). The most frequent and quickest responses are considered to be central (or prototypical) for the category. *Visual association* tests are used and work in a similar way to word association tests. Instead of words, visual stimuli and responses are used. Some of the tests give combined reciprocal antecedents that have to be remembered later on. Although the latter tests still measure properties of association, they aim more at memory and are more often used. Another class of visual tests aims at storytelling where a given set of scenes is arranged by subjects to tell or recognize a certain story. Moreover, complex external representations – like written or spoken texts or graphical visualizations – can be analyzed for their associations to look inside the structure of the learners ideas. In order to measure associatedness between a net of individual concepts (or ideas) on this level, a clear understanding and definition of the underlying syntax is necessary: Only with a suitable grammar at hand can the constructs be analyzed properly.

Important Scientific Research and Open Questions

Leaving the association psychology and also current linguistics and their very interesting experimental research behind, the field of learning and instruction usually focuses on more holistic perspectives within larger sets of associations. ► Semantic Web and ► Web Ontologies, but also large word-only association repositories such as Word-Net can be seen as implicit followers of the early structuralist approaches. Their instruments focus on gathering information from many speakers, writers, documents, and raters to determine a norm structure, e.g., of knowledge in a given domain. Other more epistemic approaches use the analysis and measurement of associations of different kinds as building blocks to describe higher cognitive constructs, e.g., mental models, schemata, subjective or naïve theories. Among the currently most important tools and algorithms to assess and measure them, Latent Semantic Analysis (LSA), Pathfinder, Think Aloud Protocols, and Structure Formation Techniques are to be named. These technologies do not focus on association alone, but they all use basic associations one way or another to describe higher-order networks of thought within individuals and groups.

Thus research on the knowledge is concerned with two aspects of mapping: First, with adding more analytic structure to the associations by adding specific functions to them, e.g., causal relations, hierarchical markers, or a system (−dynamic) functions. In other words: qualitative and quantitative properties of associations are searched for as well as how they may change over time. Secondly, the current research is also concerned with automating at least parts of the analytical processes, e.g., how to automatically identify associations, to make the measurement more feasible even for smaller research areas and practical applications that do not have the resources for a manual qualitative analysis.

Within the existing tools and instruments, different feasible ways to automatically analyze larger amounts of written and spoken language appear on the horizon, e.g., asking and answering research questions about the associations within larger linguistic entities. From the antique ideas of Aristotle until now, associations play an important role in every learning, understanding, and application of knowledge. Although the definition of higher association functions is an understandable goal for the understanding of human learning and understanding (especially of an episteme), their role within the actual knowledge performance still needs more theoretical development as well as empirical support as they do not seem to be as stable as the associations themselves.

Cross-References

- ► Aristotle
- ► Associationism
- ► Associative Learning
- ► Plato
- ► Prototype Learning Systems

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M

Measures of Correspondence

► Measures of Similarity

Measures of Similarity

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Synonyms

Judgment of similarity; Measures of correspondence

Definition

The concept of similarity defines a corresponding feature in which two objects or variables are alike. Measures of similarity provide a numerical value which indicates the strength of associations between objects or variables. The extent to which the variables are corresponding with each other is usually indicated between "0" and "1" where "0" means no similarity or exclusion and "1" means perfect similarity of identity.

Theoretical Background

The concept of similarity is widely used in almost every scientific field. Generally speaking, similarity is regarded as a numerical value which represents the equivalence between two objects, variables, items, or sets. The degree of similarity between two objects or variables is usually indicated by a standardized numerical value between "0" and "1." A "0" indicates no similarity, exclusion, or independence between the objects and a "1" means perfect similarity or identity between the objects or variables. Lin (1998) as well as Liao et al. (1998) report a variety of specific measures of similarity, e.g., information content similarity, distance-based measurements, feature contrast models, or mutual information similarity. Such similarity measures have been developed to fit to a specific domain and follow particular assumption within that domain. Accordingly, measures of similarity are in most cases not generalizable and lack a certain degree of universality (see Lin 1998).

However, there exist three major approaches to measures of similarity: (1) distance-based similarity measures, (2) feature-based similarity measures, and (3) probabilistic similarity measures.

Distance-Based Similarity Measures

The basic assumption of distance-based similarity measures is that objects can be represented in a multidimensional space. Within that space, objects which are closer to each other are regarded more similar and objects which are far apart from each other are regarded as dissimilar. Accordingly, similarity is inversely related to distance. In general, the distance-based similarity *sim* of objects *A* and *B* is defined as

$$sim(A, B) = \phi(dist(A, B))$$

where *dist* is the relation of distance having values from 0 to 1. ϕ is a decreasing function satisfying $\phi(0) = 1$. A frequently used distance-based similarity measure is the multidimensional scaling (MDS) including the Euclidean distance and city-block distance measures (Torgerson 1952).

However, the underlying axioms of distance-based similarity measures have been criticized by researchers who further developed the theoretical assumptions of similarity measures which extended the theory by introducing features of similarity (Tversky 1977) or probabilistic models of similarity (Ashby 1992).

Feature-Based Similarity Measures

In his seminal work, Tversky (1977) refers to the importance of similarity for the educational and psychological research. According to Tversky (1977), similarity is a feature-matching process. Specifically, similarity between objects is measured as a linear combination of their common and distinctive features. General assumptions of the feature-based similarity measure are that $g(A \cap B)$ denotes common features of objects *A* and *B* and that $g(A - B)$ denotes features unique to object *A*. Based on these general assumptions, Tversky (1977) developed the feature contrast model which defines the similarity *s* of objects *A* to *B* as

$$s(A, B) = \alpha g(A \cap B) - \beta g(A - \{B) - \gamma(B - A)$$

The constants α, β, and γ might be changed according to the underlying theoretical assumptions. Accordingly, the feature contrast model assumes that the similarity between objects increases through common features and decreases through unique features of the objects.

Probabilistic Similarity Measures

Taking into account that objects of variables vary over time, a deterministic similarity measure (e.g., distance-based similarity measure) might ignore important aspects of possible variations and might not be sensitive to corresponding features of the objects during these changes over time. Therefore, probabilistic similarity measures assume that an object varies probabilistically over time and that this variation is based on a well-defined transitional rule. As with deterministic similarity measures, there have been many probabilistic similarity measures proposed. Ashby (1992) provides a well-researched overview on probabilistic models and their application for educational and psychological research.

Important Scientific Research and Open Questions

The concept of similarity plays a critically important role in educational and psychological theories as well as in their empirical research. Numerous studies ask participants to make direct or indirect judgments about features of similarity of objects or variables. Markman and Gentner (1990) provide empirical evidence that a process of cognitive mapping and alignment occurs during similarity judgments. Additionally, Coombs (1964) identified similarity as an important component when evaluating products, explained as a similarity matching between a subjective ideal object and generally available objects.

Vosniadou and Ortony (1989) provide an important overview on similarity and analogy in human cognition. It is argued that similarity is essential for recognition and classification within cognitive processes. Through the integration of relevant theories and empirical evidence from psychology, education, and computer science, Vosniadou and Ortony (1989) present a fundamental piece of research. Accordingly, similarity is discussed in the light of decision making (see Kahneman and Tversky 1972), transfer of learning, approaches to instruction, and the acquisition of knowledge.

Recently, measures of similarity have been applied to computer-based diagnostics (Ifenthaler et al. 2010). The computer-based assessment and analysis instruments SMD (Surface, Matching, Deep Structure; Ifenthaler 2010), HIMATT (Highly Integrated Model Assessment Technology and Tools; Ifenthaler et al. 2010), and AKOVIA (Automated Knowledge Visualization and Assessment; Ifenthaler et al. 2010) apply measures of similarity for describing the associatedness of structural and semantic features of knowledge representations. Some of the implemented measures count specific features of a given representation. For a given pair of frequencies f_1 *and* f_2, the similarity is generally derived by

$$s = 1 - \frac{|f_1 - f_2|}{\max\ (f_1, f_2)}$$

which results in a numerical value of $0 \leq s \leq 1$, where $s = 0$ is complete exclusion and $s = 1$ is identity. The other measures collect sets of properties from the representation. In this case, the feature-based similarity measure (Tversky 1977) is applied for the given sets A and B:

$$s = \frac{f(A \cap B)}{f(A \cap B) + \alpha \cdot f(A - B) + \beta \cdot f(B - A)}$$

α and β are weights for the difference quantities which separate A and B. They are usually equal ($\alpha = \beta = 0.5$) when the sources of data are equal. However, they can be used to balance different sources systematically (e.g., comparing a learner's representation which was constructed within a short period of time to an expert model, which may be an illustration of the result of a whole book). SMD, HIMATT, and AKOVIA use seven measures of similarity: on the structural level, there is surface matching (SFM; frequency), graphical matching (GRM; frequency), structural matching (STM; Tversky), and gamma matching (GAM; frequency). On the semantic level, comparisons may be carried out as concept matching (CCM; Tversky), propositional matching (PPM; Tversky), and balanced semantic matching (BPM; derived from CCM and PPM). Ifenthaler et al. (2010) describe the individual measures of similarity and their applications in detail.

Open questions arise from the development of future methodologies and instruments for educational and psychological research. Will researchers develop new measures of similarity for specific applications or domains? Is there a universal definition for measures of similarity which combines different measures of similarity and which can be applied in different applications and domains (Lin 1998)? These open questions may be approached by interdisciplinary research projects including domain experts, psychometricians, mathematicians, and statisticians.

Cross-References

► Concept Similarity in Multidisciplinary Learning
► Role of Similarity in Human Associative Learning
► Similarity Learning

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Mechanisms in Human Learning

► Learning Mechanisms of Depression

Media

Diverse means of communication such as radio and TV, newspapers, pictures, music, and video. The term "media" may refer to the mass media, electronic media, advertising media, or other media, such as training media. Most media used in educational settings is multimedia in nature and combines sound, pictures, and video components in an interactive format.

Media and Learning

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Synonyms

Delivery systems; Learning from media

Definition

Olson and Bruner (1974) distinguish between *learning through experience* and *learning through media.* Both play a central role in the development and formation of the individual and collective knowledge of the world. However, throughout the literature on media effects, there is an important distinction made between media and methods. Whereas learning methods create the conditions for fostering competence (Glaser 1976) because they stimulate and support the cognitive processes necessary for achievement or motivation, the term *media* refers to the means of communicating information from one individual to another one. According to Clark (2001), the method that suppositionally will promote the intended learning is normally selected first, and then the media that will best deliver the information to being processed.

A central function of media consists in depicting reality or models of reality. However, the carrier of the depiction together with the conception is also labeled a medium (i.e., the technical meaning of medium). It is quite simple to classify media in accordance with their mechanical and/or electronic components, which determine the physical and technical features of media such as television, radio, textbooks, computers, etc. From the view of semiotics and cognition, the technical equipment is a necessary but not a sufficient characteristic of a medium (see Seel and Winn 1997). The central feature of media is to communicate depictions of the real or imagined world. Any (inter- and intra-individual) communication needs specific means or devices, so-called *media.*

Learning from media refers to different fields of interest. The functions of mass media, for example, differ significantly from those of instructional media due to the different contexts in which communication takes place. This entry's focus is on effects of instructional media on learning.

Theoretical Background

Effective learning and teaching with media has been at the core of instructional research and practice for decades, and actually there is not any medium or feature of a medium that has not been extensively investigated with regard to its effectiveness on learning (cf. Levie and Dickie 1973; Dörr and Seel 1997). In consequence, there is an abundance of empirical data about the effectiveness of instructional media and their features on learning. However, in summarizing former research on instructional media, Clark (1983, 1994) concluded that *media are only vehicles for delivering information* and that their effects on learning are always indirect. Only "certain elements of different media, such as animated motion or zooming, might serve as sufficient conditions to facilitate the learning of students who lack the skill being modeled" (Clark 1983, p. 453).

This conclusion evoked a controversial debate in the 1990s concerning the effectiveness of learning with media. Kozma (1991), for example, contradicted Clark's verdict from a constructivist point of view, and other authors, such as Seel and Winn (1997), focused on the semiotics of learning with media. Altogether, these authors argue that *specific media and their attributes can play an important role in learning*, and that the use of *electronic media changes the* characteristic features of *learning environments* (such as cognitive operations on representational formats, interactivity, visualization of semantic structures, feedback). Moreover, Seel and Winn conclude from instructional media research that: (1) Media have unique effects in designed instruction. (2) Media affect the perceptual organization of messages in ways that are directly attributable to their unique properties, and in so doing predispose learners to make certain interpretations rather than others. (3) Media affect how learners encode and interpret information because they are directly responsible for the nature of the mental representations that learners construct as a result of interaction with media of communication. (4) The signs and symbols that media use to convey messages can be internalized and used by students as "cognitive" tools for the construction of knowledge.

Instructional media and delivery systems should be considered as central parts of the learner's environment which can influence learning on different levels. Accordingly, we can distinguish between a *macroscopic and a microscopic level*. As Kozma (1991) pointed out, in the first case, the entire learning environment and the way in which media are integrated into it may have the greatest impact on how the students learn and think. Consequently, the larger instructional context within which the learner interacts with mediated information is of central interest. At the *microscopic level* on the other hand, the focus is on fine-grained information processing by means of sign systems. Here, the processing capabilities of an individual as well as the *semiotic functions* of the individual's interaction with a specific medium are the principal interest (cf. Seel and Winn 1997).

Important Scientific Research and Open Questions

As with all technical innovations, instructional media and delivery systems were originally used for instruction simply to do a better job with what teachers had been doing all along. As Clark (1994) points out, the hope of many scholars was always that the new media could help to achieve higher-ordered educational objectives, such as an improvement in the quality of teaching and learning, a reduction of costs, a widening of active participation of students in education, and the development of new curricular components. The implicit criterion for the success of an instructional delivery system was and is often how close it comes to emulating a successful human teacher. Indeed, the possibility of delivering the subject matter and engaging students in acting and learning requires to taking into account not only the contents to be taught but also the various components of information and communication technologies.

Instructional media and delivery systems have evolved to the point where they do have important and unique roles to play in learning. These roles have to do with creating learning environments, whether simulated or virtual, which students can explore freely or within varying constraints required by guidance in order to construct knowledge and practice problem-solving methods on their own. The key to the success of this application of media is not so much in how the "message" itself is presented, but in the degree to which students can work out for themselves ways to reduce the dissonance between what the environment presents them with and the knowledge and experience they bring with them when they enter the environment.

They relate the represented world to the "genuine" world but simultaneously they presuppose *technological literacy or fluency* as a prerequisite for learning with media. Actually, technology-based instructional delivery can be incorporated only if the audience is proficient with technology. Modern conceptions of technological literacy are often connected with two general *goals*: (1) development of skills in problem-solving and (2) development of information-managing skills (cf. Seel and Casey 2003). Today's information and communication technologies are considered as problem-solving tools with unique characteristics: (a) the new technologies are interactive systems, (b) the "locus of control" is shifted to the learner, (c) the computer can simulate experiments and model real situations, (d) immediate feedback is given to student responses, and (e) the computer can perform complex operations, for example, simulations, that are impossible or impractical on alternative media. Actually, the status of modern computer technology makes nearly all other media in the technical sense of the word obsolete and useless. The new technologies allow one to apply computer-assisted instruction, interactive videodisc instruction, integrated multimedia workstations, computer and video conferencing, and so on (Seel and Ifenthaler 2009). Additionally, the intersection of social behavior and computational systems and its impact on learning and social computing is considered as a promising development of the twenty-first century (Redecker et al. 2010).

Indeed, when we take into consideration current conceptions of teaching with new media we can see that the availability of tremendous amounts of electronic media in our daily lives has conditioned us to not investigate the associated processes of communication in instructional settings. We take them for granted, and often choose not to examine the characteristics of media and their effects on learning. But in choosing to turn away from such an examination, we lose the ability to fully understand the instructional potentials of new media. Do we know what is actually learned? Which knowledge and skills are acquired? For example, until we understand what multimedia are and what they can do, it will be difficult to understand their potential impact on learning. In particular, the capability of interfacing new information technologies for hybrid forms of audiovisual communication requires an investigation of the effects of these communicative techniques on the learner. This research has to go beyond the traditional research on instructional media because the new electronic media are not only devices for supporting instruction. Rather, they have substantially changed the characteristic features of learning environments and instructional settings (Seel and Ifenthaler 2009).

Cross-References

► Collaborative Learning Supported by Digital Media
► General Literacy in a Digital Work
► Interactivity in Multimedia Learning
► Learning Strategies for Digital Media
► Learning Technology
► Learning Through Social Media
► Literacy and Learning
► Multimedia CALL
► Multimedia Learning
► Streaming Media

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Media Effects

► Visual Communication and Learning

Media Learning

▶ Audiovisual Learning

Media Literacy

▶ General Literacy in a Digital World

Media Violence Effects on Learning

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Synonyms

Film violence; Music violence; Television violence; Video game violence

Definition

Exposure to television, film, video game, and music depictions of violence can lead to lasting changes in various knowledge structures.

Theoretical Background

Exposure to media (violent and nonviolent) has been linked with different types of learning. The General Learning Model (GLM) describes the processes by which variables, such as violent media, can produce learning (Swing and Anderson 2008). This includes not only content information in academic and professional contexts, but also learning behaviors and skills as well. For example, video game playing is associated with improvements in various visuospatial skills (Barlett et al. 2009).

Considerable research evidence also demonstrates that exposure to violent media (particularly television, films, and video games, but also music) increase aggressive behavior in both short and long-term contexts (Anderson et al. 2003, 2010). Repeated exposure to violent media can result in changes to several types of knowledge structures that together constitute personality. Specifically, repeated exposure to violent media can lead to the development of aggressive behavioral scripts, perceptual and expectation schemata, aggressive beliefs and attitudes, and desensitization to aggression.

Research also shows that prosocial TV and video games can lead to learning and enactment of prosocial knowledge structures and behavior (Barlett and Anderson in press).

Important Scientific Research and Open Questions

Additional research is needed in some areas. One concerns the potential for exposure to electronic media to result in attention deficits or executive control problems. This is of particular importance given the problematic nature of attention problems for educational contexts and the number of hours people spend on electronic media. There is evidence that viewing television in childhood and adolescence can lead to difficulties sustaining attention (e.g., Landhuis et al. 2007). Another study suggests that violent and nonviolent television (but not educational television) are associated with subsequent attention problems (Zimmerman and Christakis 2007). More recent research suggests that video game play detracts from some types of attention (Bailey et al. 2010).

More research is needed to discern whether media exposure causes attention problems, whether certain features of electronic media (e.g., fast pace, violent content) underlie deleterious effects on attention, and whether certain forms or features improve some types of attention.

Cross-References

▶ Children's Learning from TV
▶ Imitative Learning in Humans and Animals
▶ Learned Aggression in Humans
▶ Observational Learning: The Sound of Silence

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Media-Based Observational Learning

► Supplantation Effect on Learning

Medial Temporal Lobe

The part of the temporal lobe located closer to the midline of the brain. The medial temporal lobes are considered to be critical for memory formation and maintenance, and contain the hippocampi (plural of hippocampus), among other structures.

Mediated Learning Experience (MLE) and Cognitive Modifiability

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Synonyms

Cognitive Change; Cognitive Plasticity; Mediation

Definition

Mediated Learning Experience (MLE) describes a special quality of interaction between a learner and a person. *Mediated learning experiences* (MLE, Feuerstein et al. 1979) are considered as the proximal factor that explains cognitive modifiability. MLE interactions are defined as an interactional process in which parents, or substitute adults interpose themselves between a set of stimuli and the human organism and modify the stimuli for the developing child (Tzuriel 1999, 2001). *Cognitive modifiability* is defined as the individuals' propensity to learn from new experiences and learning opportunities and to change one's own cognitive structures. Feuerstein's MLE theory is in some aspects similar to Vygotsky's (1978) concepts of the *zone of proximal development* and *internalization* and the concept of *scaffolding* which have captured the interest of many developmental psychologists and educators (e.g., Rogoff 1990; Wertsch 1985).

Theoretical Foundations

In MLE, the mediator modifies the stimuli by changing their frequency, order, intensity, and context, by arousing in the children curiosity, vigilance, and perceptual acuity, and by trying to improve and/or create in the child the cognitive functions required for temporal, spatial, and cause effect relationships. The MLE processes are gradually internalized by the child and become an integrated mechanism of change within the child. Adequate MLE interactions facilitate the development of various cognitive functions, learning sets, mental operations, strategies, and need systems. The internalized MLE processes allow developing children later on to use them independently, to benefit from learning experiences in diverse contexts, and to modify their cognitive system by means of self-mediation. The more the child experiences MLE interactions, the more he/she is able to learn from direct exposure to formal and informal learning situations, regardless of the richness of stimuli they provide. Lack of MLE may be derived from two broad categories: (a) lack of environmental opportunities for mediation, (b) and inability of the child to benefit from mediational interactions, which are potentially available.

Feuerstein conceived MLE interactions as a *proximal* factor that explains individual differences in learning and cognitive modifiability. Factors such as organic deficit, poverty, socioeconomic status, and emotional disturbance are considered to be distal factors: factors that might correlate with learning ability, but which affect through the proximal factor of MLE.

Feuerstein and Feuerstein (1991) suggest 13 criteria of MLE, but only the first three, are conceived as necessary and sufficient for an interaction to be classified as MLE: *Intentionality and Reciprocity*, *Meaning* and *Transcendence*. These three criteria which are responsible for the individual's cognitive modifiability are considered to be universal and can be found in all races, ethnic groups, and socioeconomic strata. Mediation does not depend on the language modality or content and can be carried out by gestures, mimicry, and verbal interaction, provided that the three major criteria are present. The other ten criteria are task dependent, strongly related to culture, and reflect variations in cognitive styles, motivation, type or content of skills mastered, and the structure of knowledge.

The first five MLE criteria were operationalized and observed in interactions of mother–child (e.g., Klein 1991; Tzuriel 1999), peers assisted learning (e.g., Tzuriel and Shamir 2010), siblings (Klein et al. 2002), and teacher–student instruction (e.g., Tzuriel et al. 1998). The first five MLE criteria that were operationalized for research are as follows:

(a) *Intentionality and Reciprocity* refers to a mediator's deliberate efforts to change a child's awareness, perception, processing or reaction. Intentionality alone is inadequate without reciprocity. Reciprocity is defined when the child responds vocally, verbally, or nonverbally to the mediator's behavior. For instance, Intentionality and Reciprocity are observed when a caregiver intentionally offers an item to a child or verbally focuses a child's attention and the child undeniably responds. This criterion is considered crucial for the development of feelings of competence and self-determination.

(b) *Mediation of Meaning* refers to a mediator's response that conveys the affective, motivational, and value-oriented significance possessed by the presented stimuli. This can be expressed verbally by enlightening the present context, relating it to other events, and emphasizing its importance and value, or nonverbally by facial expression, tone of voice, repetitious actions and rituals. According to MLE theory, children who experience mediation of meaning will actively connect future meanings to new information rather than passively wait for meaning to appear.

(c) *Mediation of Transcendence* refers to interactions in which the mediator provides both the immediate or concrete needs of the children and attempts to reach additional goals that are beyond the specific situation or activity. In mother–child interactions the mother may go beyond the specific experience by teaching strategies, rules, and principles in order to generalize to other situations. For instance, in a play situation, the mother may mediate the rules and principles that direct a game and generalize them to other situations. Mediation for Transcendence depends on the first two criteria, intentionality/reciprocity and meaning, though the combination of all three criteria enhances the development of cognitive modifiability and expands the individual's need system.

(d) *Mediation of Feelings of Competence* is observed in interactions in which a mediator conveys to a child that he or she is capable of functioning both successfully and independently. The mediator may organize the surroundings in order to supply opportunities for success, interpret them to the child, and reward attempts to master the situation or deal with problems efficiently.

(e) *Mediation of Control of Behavior* refers to interactions in which a mediator regulates a child's reaction, depending on the child's reactive style and the task demands. The mediator may either reduce impulsivity or accelerate the child's behavior. Control of behavior can be mediated in various ways, such as arousing awareness to task characteristics and suitable responses, analyzing the task components, modeling of self-control, and providing metacognitive strategies.

An integrative component of the MLE approach is related to the conceptualization of the developing individual as an open system that is modified by mediating agents. This component has led to both theoretical elaboration of dynamic assessment (DA) of learning potential and development of an applicative system of measuring cognitive modifiability. The term DA refers to an assessment of thinking, perception, learning, and problem solving by an active teaching process aimed at modifying cognitive functioning.

Important Scientific Research and Open Questions

Most of the research on MLE interactions was carried out with the *Observation of Mediation Instrument*

(OMI, Klein 1996) applied in combination with videotaping of interactions. Cognitive modifiability was measured by DA using change criteria. The conceptualization behind using change criteria as predicted outcome of MLE interaction is that measures of modifiability are more closely related to mediational processes by which the child is taught how to process information, than they are to standardized static measures of intelligence. The mediational strategies used within the DA procedure have more "matching value" to learning processes in other life contexts than do conventional static methods and therefore give better indications about future changes of cognitive structures. Accumulating evidence from educational research provides indications that a score reflecting individual differences in "modifiability" added substantially to the predictive power of learning (Embretson 1992) and future academic success (Tzuriel et al. 1999).

Research findings show that the higher is the criterion score saturated with teaching effects (gain score as compared with pre-teaching score within a DA measure), the higher was the variance contributed by MLE mother–child processes in prediction the cognitive score (Tzuriel and Eran 1990). *Mediation for Transcendence* and mediation of *Regulation of Behavior* were found repeatedly as the strongest predictors of *children's cognitive modifiability as indicated by post-teaching scores in DA* (Tzuriel 1999). Both MLE criteria reflect a typical mother–child interaction in which the mother is involved in mediating rules and principles (Transcendence) and monitoring (regulating) the flow of the children's behavior (Tzuriel and Ernst 1990; Tzuriel and Shomron 2009; Tzuriel and Weiss 1998; Tzuriel and Weitz 2007). In several studies, the relative effects of distal and proximal factors (e.g., MLE processes) on cognitive modifiability were investigated. The overall results of the SEM analyses were congruent with the MLE theory according to which proximal factors explain individual differences in children's cognitive functioning, whereas distal factors (i.e., SES-level, child's personality, mother's acceptance–rejection of the child) do not have a direct effect on children's cognitive factors, though they do explain some of the proximal factors.

Recent research of peer mediation showed that children participating in a *Peer Mediation with Young Children (PMYC)* program improved their MLE strategies (e.g., Shamir and Tzuriel 2004) as well as enhancing their *cognitive modifiability* (Tzuriel and Shamir 2007, 2010) and math performance (Shamir et al. 2007; Shamir and Tzuriel 2004). Thus, children who learn how to mediate become not only better mediators (tutors) but also better learners, as reflected in their cognitive modifiability scores. In Vygotsky's (1978) terms, the peer-mediation experience enabled the tutors to advance from a *lower* zone of proximal development (pre-intervention) to an *upper* zone of proximal development (post-intervention).

Cross-References

▶ Family Background and Effects on Learning
▶ Family Learning
▶ Home Schooling and Teaching
▶ Learning in the Social Context
▶ Mediators of Learning
▶ Peer Learning and Assessment
▶ Social Learning

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Mediated Signs

► Affordance and Second Language Learning

Mediation

► Affordance and Second Language Learning
► Mediated Learning Experience (MLE) and Cognitive Modifiability

Mediators of Learning

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Definition

The term "mediators of learning" refers to agents of learning that use meditated learning experience (MLE) strategies to enhance their learning capacities (see *mediated learning and cognitive modifiability* for definition of MLE strategies). Mediators of learning are typically parents, siblings, teachers, caregivers, peers, and grandparents.

Theoretical Background

Most research on mediators of learning focus on the role of parents and peers with very few studies on the role of sibling, caregivers, teachers, and grandparents.

Parents

Parents mediating interactions with their children's during early childhood provide the first culture of learning (Cole 1990). As children learn to how to solve problem, parents provide support when tasks are too difficult. Parents' support (scaffolding) of their children's problem solving includes providing cognitive support, transferring responsibility when the child is capable of managing the task independently, and motivating the child to complete the task. Many researchers have found that specific activities of parents relate to their children's cognitive development, both concurrently and predictively, and that both the child and the parent influence the child's mental development (Berk and Spuhl 1995; Klein 1996; Tzuriel 1999).

Klein's studies with infants (e.g., Klein 1996) showed the amount of mediation parents gave to their infants was more strongly related to the children's cognitive development than were commonly used measures of early cognitive performance. In general, 10 min of observation of MLE interactions when the children were 12 months old could predict the children's cognitive performance at 48 months of age. Intervention studies with mothers showed that mothers who were trained how to mediate to their children showed higher quality of MLE strategies, that the mediation behavior was sustained over several years and that the children's cognitive performance was improved more than those shown in a control group. Tzuriel's studies with kindergarten and school age children showed that parental MLE strategies predicted children's cognitive modifiability among different groups of typically developing children and learning disabled children. The most powerful strategies were mediation for transcendence (i.e., expanding) and self-regulation. Of most importance were findings showing that the proximal factor of parental MLE strategies explained cognitive modifiability whereas distal factors such as SES, child personality orientation, and mother's acceptance/rejection of the child did not explain the child's cognitive modifiability. The distal factors explained the MLE strategies which in turn affected directly the child's cognitive modifiability (e.g., Tzuriel 1999, 2001).

Siblings

Older siblings were found to posses meaningful role models to their younger siblings, thus affecting their cognitive, social, and emotional development (Azmitia and Hesser 1993; Maynard 2002). Azmitia and Hesser (1993) reported that siblings used more frequent spontaneous guidance and provided more positive feedback in their interactions with younger preschool siblings in a teaching situation than with peers. These behaviors were related to the younger siblings' demands for explanation and requests to gain control over the performance, which were expressed more frequently toward older siblings than toward peers. Vygotsky's (1978) concept of "apprenticeship" is particularly meaningful in the present context. Apprenticeship (Wertsch 1985) describes learning that takes place during natural daily activities. It is built upon interactions between older and younger members of a cultural group where the older sibling "scaffolds" the abilities of the younger during a shared performance, and involve culturally relevant tasks and activities. The finding showing that younger siblings' demand for learning was related to the efficient teaching strategies of older siblings highlights the bidirectional nature of learning in the sibling context. It seems that the familiarity between siblings not only facilitates the older sibling's teaching strategies, but also promotes the younger child's skill in asking adequate questions and eliciting concrete instructions from the older experienced sibling, resulting in a more efficient process of *guided participation*. Studies using the MLE model (e.g., Klein et al. 2003) showed that the frequency of mediation behaviors in 5-year-old children mediating to their 3-year-old siblings was found to be related to the younger siblings' success on games that were taught. The meditational behaviors of older siblings were characterized by relatively high frequencies of regulation of behavior and encouraging. The differences in MLE strategies between dyads of siblings in which the younger sibling has an intellectual disability (ID) as compared with dyads of typically developing (TD) siblings was investigated by Hanukah-Levy and Tzuriel (2007). The findings showed that in all MLE strategies, the highest mediation was given by older siblings in the ID group (except in Transcendence strategy). These findings indicate that the older siblings in the ID group were aware to the special needs of the young ID siblings above and beyond the existing mental age, and therefore, spontaneously compensated for their unique difficulties by providing higher level of mediation.

Caregivers

The effects of childcare setting on learning outcome are controversial. On one hand, childcare quality and time spent in childcare were found to predict positively developmental outcomes of children who attended childcare, even after controlling for family selection factors such as socioeconomic status, maternal education, parenting, and family structure (Belsky et al. 2007). On the other hand, earlier reports revealed that family factors did not predict cognitive development differently for children who do and those who do not experience childcare (NICHD Early Child Care Research Network 1998). These large-scale studies did not relate to specific MLE strategies. Klein developed *the Mediational Intervention for Sensitizing Caregivers* approach (MISC; Klein 1992) as a tool for enriching the quality of interaction between caregivers and children. One of the characteristics of the MISC is helping the caregivers focus on criteria of the quality of interaction that are content-independent and that can be transferred to a variety of situations. The MISC was efficiently applied with typically developing children (Klein 1992, 2003), children with Down's syndrome (Sobleman-Rosenthal and Klein 2003) and PDD (Greenspan and Weider 1998), and intellectually disabled adults (Lifshitz and Klein 2007).

Important Scientific Research and Open Questions

Promising MLE approaches such as the *Bright Start* program (Haywood, et al. 1986), *Mediational Intervention for Sensitizing Caregivers* (MISC, Klein 2003), *Peer Mediation with Young Children* (PMYC, Shamir and Tzuriel 2004; Tzuriel and Shamir 2007), and *Analogical Reasoning Program* (ARP, Tzuriel and George 2009) are aimed at enriching the quality of MLE strategies between caregivers and children and consequently the children's cognitive performance. The Bright Start program was found as effective in developing the mediation teaching style of kindergarten teachers as well as enhancing children's cognitive modifiability and academic achievements of different clinical groups of children (Tzuriel et al. 1999; Tzuriel et al. 1998). The MISC was proved to be effective for enhancement of learning with typically developing children (Greenspan and Wieder 1998; Klein 1996) as well as with intellectually disabled individuals (Lifshitz and Klein 2007). The PMYC was found effective in developing mediated learning strategies of mediators as well as their cognitive modifiability and school achievements, and the ARP was found as an efficient program for developing analogical reasoning and math skills.

Peers

The effects of peer-assisted learning on children's learning and academic achievement have been investigated extensively during the last two decades (e.g., Rohrbeck et al. 2003). The concept of peer mediation was developed recently (e.g., Shamir and Tzuriel 2004; Tzuriel and Shamir 2007) following studies about the effects of mother–child MLE strategies on children's cognitive modifiability (e.g., Tzuriel 2001). Recent research has shown that Peer Mediation with Young Children (PMYC) program was effective in improving MLE strategies of young children (e.g., Shamir and Tzuriel 2004) as well as enhancing their *cognitive modifiability* (Tzuriel and Shamir 2007, 2010) and math performance (e.g., Shamir, et al. 2007). Moreover, the findings indicate that tutees who themselves did not receive any training program but were taught by their peers trained in using MLE strategies showed also a higher level of mediation strategies (Shamir and Tzuriel 2004) and a higher cognitive modifiability on seriation tasks (Tzuriel and Shamir 2007) and in math (Shamir et al. 2007) than did their peers who were taught by non-mediating tutors. Repeated findings indicate that children who learn how to mediate to their peers internalize the MLE strategies and become themselves better learners in other contexts.

Grandparents

In today's reality, the ties between children and their grandparents are stronger than in the past, and grandparents are increasingly playing a significant role in the lives of their grandchildren and in intergenerational transmission of parenting skills. Most grandparents see their grandchildren at least once a month, sometimes much more often. The relationship is seen generally by both generations as positive and important. Grandparenting role is diverse; the grandparent provides the grandchild love and affection, care, shelter, life experience, moral values, company, closeness, trust, aid, and support. Studies on the role of grandparents as mediators were carried out with the objectives to investigate differences between mediation strategies of mothers and maternal grandmothers as well as the similarities in mediation style as indicative of transgenerational transmission of mediation strategies (Isman and Tzuriel 2007). Findings indicate that grandmothers tend to mediate intentionality and reciprocity (i.e., focusing), meaning (i.e., labeling), and transcendence (i.e., expanding) on a higher level than mothers. On the other hand, mothers tend to mediate regulation of behavior on a higher level than grandmothers. These findings may be explained by the fact that grandmothers are more experienced mediators than mothers. They intuitively know what the child needs in order to learn effectively; therefore, when focusing the child, they choose to elaborate mediation of meaning and transcendence. The mothers' higher level of self-regulation strategy might indicate her higher level of responsibility for her child's development, hence her efforts to monitor the child's behavior. Correlations between grandmothers and mothers MLE strategies revealed that in a structured situation (e.g., teaching task), four out of five criteria emerged as significant: *intentionality and reciprocity* ($r = .26$), *transcendence* ($r = .34$), *feelings of competence* ($r = .52$), and *regulation of behavior* ($r = .25$). The resemblance between grandmothers' and mothers' level of MLE criteria may indicate a certain level of transmission of MLE strategies from generation to generation.

Cross-References

- ▶ Family Background and Effects on Learning
- ▶ Family Learning
- ▶ Home Schooling and Teaching
- ▶ Learning in the Social Context
- ▶ Mediated Learning and Cognitive Modifiability
- ▶ Peer Learning and Assessment
- ▶ Social Learning

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Meditation, Memory, and Attention

► Attention, Memory, and Meditation

Medium

► Cue Summation and Learning

Membership

► Identity and Learning

Memory

Refers to the ability to store, retain, and recall information and experiences. This ability allows one to use past experience to plan future actions.

Cross-References

► Video-Based Learning

Memory Adaptation

► Adaptive Memory and Learning

Memory Aids

► Mnemonic Learning
► Mnemotechnics and Learning

Memory Capacity

Memory capacity is an important performance measure for associative memories. Different definitions coexist. For example, memory capacity has been quantified as the number of retrievable memories per neuron (Hopfield 1982) or the total information that can be retrieved normalized by the number of synapses (Willshaw et al. 1969). The information-theoretic definition of memory capacity is more general, for instance, it can be used to assess how sparseness in the memory patterns affects the performance of associative memory.

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Memory Code

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Synonyms

Neural memory algorithm

Definition

The term *memory code* refers to a relationship that describes the transformation of a cardinal aspect of experience into an enduring neural form. Memory codes may be appreciated by comparing them with sensory codes, the operation of which enables the representation of

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a sensory parameter by neural activity. For example, the loudness of a sound may be represented as an increasing rate of discharge of auditory system neurons: the louder the sound, the greater the rate of discharge. However, unlike sensory codes, *memory codes* provide for the long-term representation of a general attribute of experience. For example, the *behavioral importance* of an experience might be represented as an increasing function of the number of neurons that represent that experience (Weinberger 2001).

Theoretical Background

Views on the nature of memories differ. Some workers regard them as somewhat veridical records of experiences while other consider memories as reconstructions based on bits and pieces of stored information, subject to a host of other processes that compromise accuracy. Undoubtedly, different forms of memory are differentially subject to these problems and the list of variables that affect memory strength and memory clarity is known to be long and surely is still incomplete. Nonetheless, whatever one's views about the veracity of memories, for memory as a fundamental competency of the brain to have any function at all, for organisms to derive any benefit from past experience, there must be the storage of *sufficient correct detail* to support future adaptive behavior.

Memory storage has at least two faces: the *specific content* of an experience, e.g., "Was that car red or blue?"; the *meaning* of an experience, e.g., "Did that car almost hit me?". It is generally agreed that the more important an experience, the greater will be its strength. For example, traumatic experiences are generally more difficult to forget and less subject to interference or conflation than less meaningful experiences. At the extreme, memories can be intrusive as in post-traumatic stress disorder (PTSD). The basolateral amygdala (BLA) is thought to be a major mechanism that modulates the strength of memories via its reactivity to stress hormones that are secreted by the adrenal glands (McGaugh 2004). But as most memories are not traumatic, yet enduring (e.g., your mother's maiden name), they must have a neural substrate which enables their maintenance. One way in which this could be accomplished is by the instantiation of memory codes for particular features of memories. While general neural algorithms for the representation of the specific content of individual experiences are unlikely because of the unique aspects of particular occurrences, memory codes could be used to represent fundamental features that are common to all memories.

Important Scientific Research and Open Questions

Currently, there is some confusion among the terms *memory code*, *memory encoding*, and *engram*. Memory encoding refers to the psychological level strategy employed to represent a stimulus or event. For example, the spoken word "bird" could be encoded as the animal to which it refers (semantic level of encoding) or as the sound of the word itself (phonological level of encoding). The term *engram* is usually employed to refer to the *totality of neural changes that comprise a memory*, whether stored in a local or distributed manner.

A memory code is neither a psychological level strategy nor the actual neural substrate of a memory. Rather, a memory code denotes a particular type of "input–output" function. A memory code describes the transform from, e.g., patterns of sensory-derived neuronal discharges [INPUT] into long-lasting changes in neural organization that represent a cardinal feature of memory [OUTPUT].

The major current issue is whether memory codes are merely hypothetical constructs or actually are instantiated by brains. There is now direct evidence for a memory code for the *behavioral importance of a sensory event*, one that operates (perhaps surprisingly) in the primary auditory cortex. For example, the relative behavioral importance of a tone was manipulated in rats trained to bar-press for water reward in the presence of that tone. The area that represented the frequency of this tonal signal in (the "tonotopic map" of) the auditory cortex was expanded as an increasing function of the level of its behavioral significance (Rutkowski and Weinberger 2005). Insofar as important memories are more resistant to interference, such as in behavioral extinction, one might expect that the stronger the memory, the larger the area of cortical representation and the slower its extinction. This relationship also has been found (Bieszczad and Weinberger 2010).

Research on memory codes is still in its early stages, perhaps because most brain-memory studies are concerned with the processes responsible for memory storage while inquiry on how the brain represents *memory content* has lagged. The nascent status of memory codes clearly provides many opportunities for additional inquiry.

Cross-References

- ▶ Memory Consolidation and Reconsolidation
- ▶ Memory Persistence
- ▶ Mental Representations
- ▶ Sensory Memory

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Memory Consolidation

▶ Dreaming: Memory Consolidation and Learning

Memory Consolidation and Reconsolidation

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Synonyms

Memory storage; Restabilize; Re-storage; Stabilize; Time-dependent processes

Definition

The terms *consolidation* and *reconsolidation* are theoretical constructs closely, but not exclusively, linked to the phenomenon of retrograde amnesia. The term "consolidation" refers to the presumed underlying neural processes involving the storage of memory that would account for the time-dependent characteristics of retrograde amnesia, in which recent information is more vulnerable than older information. Reconsolidation represents a special case in which an old memory that has been reactivated by exposure to the learning situation becomes susceptible to an amnesic event. Thus, reconsolidation involves the putative neural mechanisms involved in re-storage of memory. Both terms are also used in a more descriptive sense to refer to a variety of findings indicating that processing of information in animals as well as humans can continue for a short period of time after an input or event has ended.

Theoretical Background

That traumatic closed-head brain injury such as concussion could lead to forgetting of earlier events or retrograde amnesia (RA) has long been recognized. In addition, clinical observations in the 1800s on patients with traumatic brain injuries suggested that memory for events shortly before the injury were more likely to be forgotten than memory for earlier events. This finding of a temporal gradient of memory loss, based on case studies, became an important aspect of what came to be referred to as consolidation. Similar observations were later made when patients undergoing electroconvulsive shock therapy (ECT) for depression seemed to forget events just before the ECT treatment but not earlier ones. These informal findings were subsequently verified experimentally. Patients learned two lists of material, one shortly before ECT and the other several hours prior to treatment. When the patients were tested, the memory loss was greater for the more recently learned material.

The term "consolidation" seems to have originated with laboratory work with humans done by Muller and Pilzecker in their studies on retroactive interference. It appeared that interpolating the new information shortly after the target material was acquired was more detrimental to the original memory than interpolating the second material after a delay. Although their finding has not held up in more recent studies, that outcome and related observations led them to suggest that during learning the information persisted or perseverated in memory for a brief period after an event. They concluded that newly acquired information had to undergo a period of "consolidation" in order to become stable. Other investigators quickly realized that this concept would be relevant to the observations on retrograde amnesia.

The inherent limitations on using humans in studies led to the use of nonhuman animal models (primarily rodents) in laboratory studies of RA. One early investigation trained rats to avoid foot-shock in an active avoidance task where each trial was followed by ECS after one of several different delay intervals. Consistent with the human literature, RA diminished as the delay between a trial and the ECS increased, and at the longest delay of several hours the experimental rats performed as well as the sham ECS (control) group. As this finding showed, an important implication of the temporal gradient was that the memory deficit was not due to gross brain damage or general memory impairment.

One interpretative problem that arose with respect to the early laboratory studies of RA was that the temporal gradient might result from a punishment effect if the amnesic agent were even momentarily perceived as aversive. Poor performance might be temporally graded due to suppression from punishment rather than memory loss. The issue was resolved by the introduction of the "inhibitory avoidance" (also called passive avoidance) paradigm, in which subjects had to refrain from making a response that was explicitly punished by foot-shock. When the training was followed by the amnesic treatment, the memory failure interpretation correctly predicted that the subjects would repeat the response, while a suppression of performance view would predict the opposite outcome. Two further advantages of the inhibitory avoidance task were that: (1) it was learned in a single trial, thus allowing a precise specification of the temporal gradient, and (2) in control groups the response was well retained over long intervals of time.

A seminal paper by McGaugh (1966) reviewed the evidence for time-dependent effects when manipulations (drugs, ECS, etc.) were introduced following conditioning. He noted that this arrangement precluded potential problems with sensory, motivational, or associative processes that could occur with manipulations that occur before training. Although many treatments produced impairment of memory, some could enhance memory, and both outcomes were consistent with the notion of consolidation of storage. Thus, consolidation implied a temporarily labile state that became more stable over time. This concept was further supported by the neurobiological speculation that learning or perceptions initiated neuronal activity that persisted shortly after the event in the form of "reverberating circuits" that provided the underpinnings of storage.

These findings and concepts combined to provide an appealing account of retrograde amnesia: The time-dependent effect reflected the cessation of storage when the amnesic agent disrupted the neuronal activity. With longer delays, more of the information was already stored. As agents that can inhibit protein synthesis can induce amnesia, many investigators have come to focus on that synthesis as the more specific mechanism involved in consolidation. Currently, a common, but not universal, view is that protein synthesis is the process underlying consolidation.

A major implication of consolidation theory was that memory, once consolidated, became relatively impervious to amnesia. This view was challenged when Misanin et al. (1968), using ECS, reported obtaining retrograde amnesia for old memory that had been reactivated by a brief exposure to the training cue (CS). They suggested that the level of activity, rather than age of the information, was the key determinant of vulnerability. Although other labs reported conceptual replications of amnesia for "old but reactivated" memory, the issue did not attract much attention until many years later when a paper by Nader et al. (2000) appeared from a behavioral neuroscience laboratory. That study showed that inhibition of protein synthesis in the basolateral amygdala resulted in RA for a reactivated old memory. By demonstrating amnesia in a highly analytic and extensive study, Nader's finding captured the interest of many neuroscientists. Along with that came a shift in research strategies from primarily behavioral to much more molecular. The term "reconsolidation," although not new, became a convenient label for the basic phenomenon.

Important Scientific Research and Open Questions

Despite the appeal of the consolidation model, it has undergone both some modifications and some theoretical challenges in recent years. With respect to brain areas of importance for consolidation, a traditional view has been that the hippocampus serves as a temporary repository for new information, and that over time the memory is transferred to neocortical areas for more permanent storage. One apparent difficulty with this view has been the evidence from some studies of temporal gradients of RA extending back for weeks (animals) to years (humans). These findings led to a distinction between relatively brief "cellular consolidation" (minutes to hours) and "systemic consolidation" that might continue for years. A few studies have even reported gradients extending back for years as a result of various brain lesions. However, an alternative view that can explain long temporal gradients independently of an extended consolidation process involves multiple traces: Older memories are more likely to have been reactivated at various times, thus establishing multiple neocortical traces that would attenuate or prevent amnesia. Furthermore, a very flat gradient could imply that retrieval or other associative mechanisms have been disrupted rather than that storage is impaired.

The issue of reversibility or attenuation of amnesia has been a source of contention. A number of studies have found that various reminder manipulations short of retraining can alleviate RA resulting from agents such as ECS and hypothermia. In some cases reexposure to the amnesic agent itself can produce at least partial recovery of memory. The latter outcome has led retrieval-oriented researchers to propose a modified state-dependent interpretation of both consolidation and reconsolidation (Riccio et al. 2006). According to that view, new information (or reactivated information) continues to be processed for a short period after the event. This post-acquisition (or post-reactivation) processing becomes associated or encoded with the unique internal state produced by an amnesic agent. At later testing, the memory is not retrieved as the state is no longer present; however, reexposure to the agent will provide the necessary state (retrieval) cues. This interpretation, based on the importance of a match between encoding and retrieval contexts, provides an alternative account of the temporal gradient, since with longer delays more of the information is encoded in the normal state.

A central question with respect to reconsolidation, assessed in terms of amnesia, involves comparison with amnesia for new memory. An early behavioral study by Mactutus et al. (1982) found both similarities and differences between the two phenomena with respect to several characteristics. More recent research has begun to examine the molecular bases for consolidation and reconsolidation and has yielded contrasting results. One major issue has been whether reconsolidation involves destabilization of the established memory and the need for new protein synthesis to occur again. From this perspective, amnesia for reactivated old memory reflects the disruption of de novo protein synthesis. For instance, infusing the protein synthesis inhibitor anisomycin into the lateral and basal nuclei of the amygdala as well as the dorsal hippocampus shortly after reactivation of an old fear memory has been reported to result in persistent amnesia for that memory. This suggests that a fear memory returns to a labile state once reactivated and the reconsolidation of that memory requires de novo protein synthesis. Other laboratories have found further evidence that consolidation and reconsolidation share similar molecular properties. For example, the transcription factors cyclic AMP-response element binding protein (CREB) and zinc finger 268 (zif268) appear to be required for both consolidation and reconsolidation of contextual fear conditioning in mice and object recognition in rats, respectively (for further review see Alberini 2005). However, other laboratories have either failed to find protein synthesis-dependent reconsolidation or have found transient effects of protein synthesis inhibitors on reactivated memories (i.e., recovery from amnesia) suggesting that reactivation of an old consolidated memory does not result in a destabilization and subsequent re-stabilization of the memory. In addition, several laboratories have found certain molecular mechanisms that are unique to consolidation and reconsolidation. The transcription factor CCAAT enhancing binding protein ß – (C/EBP ß) has been found to be required for consolidation within the hippocampus for inhibitory avoidance learning, but not for reconsolidation. However, C/EBP ß within the amygdala is required for reconsolidation of inhibitory avoidance learning, but not consolidation. Although a clear picture of common versus unique features has not yet emerged it seems fair to conclude that reconsolidation involves some mechanisms that are different from consolidation.

Operationally, the procedure of reexposure to the training conditional stimulus to reactivate memory in reconsolidation is identical to the procedure for producing extinction. This raises the question of whether the poor performance at testing might reflect an extinction effect rather than "memory impairment." Several lines of evidence argue against the extinction interpretation. For example, the short duration of exposure used for reactivation produces little extinction in controls. Also, reactivation of old memory can be achieved by exposure to stimuli (such as the unconditional stimulus) that are unrelated to extinction.

In terms of application, the potential modifiability of an old but reactivated memory in anxiety-related disorders has become of interest to researchers concerned with the therapeutic implications of reconsolidation.

While arguments about the nature and even existence of consolidation exist, at an empirical level there is little doubt that processing of information continues after an event. The time-dependent characteristics of directed forgetting, transfer of retrieval cues, trace conditioning, and other phenomena all attest to the fact that some type of neural activity persists for a period of time.

Cross-References

- ► Amnesia and Learning
- ► Dreaming as Consolidation of Memory and Learning
- ► Extinction Learning
- ► Internal Reinforcement Hypothesis
- ► Linking Fear Learning to Memory Consolidation

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Memory Dynamics

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Synonyms

Deformation; Degradation; Formation; Persistence; Reappearance of memories; Strengthening

Definition

Memory is generally associated to the permanent retention of past experiences. However, it appears that some past experiences persist over very long delays in the memory repertoire while others are rapidly forgotten in the face of various constraints or perturbations. In the field of experimental psychology, memory is tested by requiring participants to practice a novel task with a model in order to *learn* it. Then, a retention interval corresponds to a rest period during which participants do not practice the task. Finally, the model is suppressed and participants are invited to *recall* the practiced task from memory. During this stage, the memory can undergo very different evolutions such as persistence, strengthening, degradation, deformation, or reappearance. ► Memory dynamics precisely refers to all these possible changes of memories as function of time, environmental constraints, or perturbations. Persistence and forgetting can be considered as two adaptive processes that render memory sometimes *robust* – i.e., able to adopt persistent behaviors in spite of perturbations – and sometimes *flexible* – i.e., able to adjust to such perturbations.

Theoretical Background

Experimental psychology aims at finding general laws that account for various situations and individuals. In this field, a central theoretical and practical challenge is to find some behavioral signs that enable to predict the memory dynamics. This question has been studied for more than one century, and two theoretically distinct approaches have emerged: the so-called "traditional" and "dynamical" approaches of learning and memory. These approaches not only differ in terms of their origins and theoretical conceptions of memory, but also in terms of experimental paradigms and measures of memory dynamics.

The traditional approach is based on the *cognitive theory* that emerged in the 1950s with the revolution of engineering sciences, logic mathematics, and computer sciences (Gardner 1985) and is still nowadays the dominant approach to learning and memory. A key idea is that the functioning of human mental processes, such as memory, can be inferred from the understanding of computer functioning. The central nervous system (CNS) is thus considered as an information processing system which *encodes* environmental information as a symbolic representation, *stores* it during the retention interval, and *retrieves* it when recall is required. It implies that once encoded, memories are stored in a static and permanent form. Forgetting is thus defined as a loss of information, and researchers set out to identify the possible system failure leading to this loss of information according to two distinct conceptions.

The idea of the *structuralist conception of memory*, inspired by the British psychologist Edward Titchener (1867–1827), is that memory can be divided into different systems located separately in the brain and storing information according to its nature (declarative, procedural,...). Forgetting would thus result from a structural damage of the system that stored the lost information. This explains why information stored in the declarative memory system (concerned with knowing "that he did") can be lost without losing information stored in the procedural memory system (concerned with knowing "how to do"). For example, one can forget that he was riding a bicycle last week without forgetting how to ride a bicycle. A different idea of forgetting is postulated in the *functionalist or proceduralist conception of memory*. This conception, originally inspired by the American psychologist William James (1842–1910), assumes that records of past events are stored in a unique reservoir. Forgetting is thus attributed to a problem in the encoding or retrieval processes rather than storage. More precisely, the encoding context or the processes at work during practice would influence the retrieval probability at recall. For example, changing the context (location, mood, etc.) between the encoding and the retrieval stages would increase the likeliness of forgetting. All in all, both the structuralist and functionalist memory conceptions consider forgetting as an ineluctable loss of information during encoding, storage, or retrieval. However, both conceptions overlook that memories can undergo different fates and spontaneously evolve over time, suggesting that they are not stored as an exact replica of the past experiences.

Memory dynamics is precisely at the heart of pioneer theories of memory functioning. Considering that forgetting can take different forms, researchers assume that memories are not stored in a static and permanent form. Instead, memories can be viewed as changing representations of the past. The key question is thus to identify the processes underlying these changes. This question has been debated in the light of two different conceptions deeply rooted in ancient memory metaphors introduced by philosophers in the seventeenth century (Koriat and Goldsmith 1996). First, the *storage metaphor* is inspired by the *empiricist* philosophical point of view (Locke 1632–1704) which considers memory as a tabula rasa on which traces are progressively written and laid down, like discrete copies of past events that passively wait for a possible retrieval. Operationally, the number of retrieved memories decreases over time. Hence, *theories of forgetting* postulate that the memory traces disappear progressively: they can deteriorate with the passage of time in the absence of retrieval, as postulated in the Ebbinghaus' *decay theory* (1885), or they are replaced by other memory traces from past or recent learning, as proposed by Müller and Pilzecker in the *interference theory* (1900). In contrary, the *metaphor of correspondence* is founded upon a *rationalist* philosophical point of view (Descartes 1596–1650) suggesting that memory is pre-organized in generic and abstract internal representations of past experiences called *schemas*. Experimental findings on repeated recalls of the same memory revealed that the performance tends to a more and more simple and familiar representation of the past, possibly leading to false memories. On this basis, Bartlett's *distortion theory* (1932) posits that retrieval is a reconstruction of the past so that pre-existing familiar memories are integrated in the memory trace. Forgetting corresponds to a memory distortion (i.e., a deformation) of the correspondence between the actual past event and its memory trace due to the active intervention of an internal schema already existing in memory. To sum up, the two metaphors of memory concentrate on (1) the nature of the representations in memory (discrete traces or schemas) and (2) the multiple processes by which the representations are deteriorated (disappearance or reconstruction). However, in no way these theories address the question of the formation, persistence, and possible reactivation or strengthening of memories.

More recently, a radically different approach of learning and memory has emerged. The *dynamic pattern approach* aims at describing, understanding, and predicting the formation, persistence, disappearance, and reappearance of behaviors in the face of various constraints or perturbations (Kelso 1995). This approach is interested in open complex systems (e.g., climate system, CNS, socio-economic system) which are continuously exposed to environmental constraints or perturbations that tend to change the ongoing behavior. Thus, a challenging purpose in this field is to identify the conditions and underlying processes leading to the persistence of a given behavior in spite of these perturbations. To address this question, dynamic pattern approach borrows the concepts from *self-organization theories* developed in the field of living and physico-chemical sciences and the mathematical tools of *dynamic systems*. Examples coming from non-equilibrium thermodynamics, pioneered by the Nobel price winner in chemistry Ilya Prigogine (1917–2003), suggest that such systems adopt a limited number of *preferred patterns* (i.e., organized configurations) depending on the external conditions. Patterns emerge, persist, disappear, and reappear spontaneously in face of changing external constraints, without the intervention of an internal representation which prescripts a specific behavior. Formalization of the nonlinear patterns' evolution in response to linear changes of external constraints allows predicting the dynamic behavior of the system.

On this basis, dynamic pattern theory (DPT) of human behaviors developed from the middle of the 1980s. (see Kelso 1995) It defends that CNS is an open complex system governed by the generic processes of self-organization. Experiments are mainly conducted in the field of perceptual-motor coordination. Preferred patterns constitute the memory repertoire. They are characterized by their stability that is the property to return rapidly to the initial state after a perturbation has moved it away (Haken 1983). Experimental findings on bimanual coordination show that a coordination pattern remains stable as long as the external constraints (e.g., movement speed) respect the range of possibilities of the system. When external constraints increase and become critical, the pattern suddenly destabilizes and may switch spontaneously to a more stable pattern. In this case, the pattern cannot be produced anymore. However, it disappears definitely from the memory repertoire: Once environmental constraints turn back to the range of possibilities of the system, the pattern can reappear. It follows that only the most stable patterns can persist in response to increasing environmental constraints or perturbations. Thus, stability (and loss of stability) is thus a key property accounting for both robustness (persistence) and flexibility (forgetting and reappearance) of the system in response to external changes.

Important Scientific Research and Open Questions

The first important finding in the field of DPT is that memorizing a new bimanual coordination pattern implies a *competition* between the to-be-learnt pattern and the stable patterns pre-existing in the memory repertoire. Competition can be reduced by two processes that differ in stability during practice and guarantee the robustness and flexibility of the memory system after practice.

(1) An increase in accuracy without stabilization of the to-be-learnt pattern reduces transiently the competition and reflects a *simple adaptation of a pre-existing stable pattern* during practice. At recall, the to-be-learnt pattern is forgotten and the pre-existing stable pattern reappears. This form of forgetting can be viewed as an adaptive process which ensures the flexibility of the memory system because (a) it allows transient adaptation to various environmental constraints, (b) it avoids uncontrolled multiplication of persistent memories (e.g., hypermnesia occurring in savant autism), and (c) it limits excessive rigidity of behaviors (e.g., perseverations occurring in frontal damages).

(2) The stabilization of a new pattern during practice annihilates the competition with pre-existing stable patterns and leads to the *creation of a new stable and persistent pattern* in the memory repertoire. If the stabilized pattern does not correspond to the to-be-learnt one, a persistent false recall is created. It follows that the long-term persistence of a new pattern in memory depends on the stabilization process during practice, whatever the accuracy may be. Neuroimaging studies suggest that the stabilization process go with the formation of a specialized neural network (e.g., Debaere

et al. 2004). It remains to know if this neural specialization could be the correlate of pattern persistence at recall, and possibly of its consolidation – i.e., the increase in resistance to interference over time, as first discovered in 1900 by Müller and Pilzecker.

Second, DPT suggests that the creation/stabilization of a new persistent stable pattern can be predicted before practice. Recent findings comfort Schöner's prediction (1989) according to which the resolution of the competition depends on the stability of the nearest stable patterns pre-existing in the memory repertoire. Creation of a new stable and persistent pattern occurs only if the initial competition is strong enough, i.e., if the pre-existing patterns are enough stable. Given that each individual presents his/her own memory repertoire, this highlights the crucial role of the *inter-individual differences* existing before practice to predict which pattern can integrate the memory repertoire and persist after practice. This explains that a given memory system cannot integrate all information equally and undergo different memory dynamics.

Third, DPT opens new perspective on the memory dynamics dysfunctions such as Parkinson and Alzheimer diseases that present difficulties in learning and recall of new procedural or declarative memories. These memory disorders could reflect troubles in the stabilization process. Even if this hypothesis needs experimental validations, it is possible that the patterns pre-existing in the memory repertoire are not enough stable to create competition leading to the creation of new persistent patterns.

Cross-References

▶ Ebbinghaus, Hermann (1850–1909)
▶ Individual Differences in Learning
▶ James, William (1842–1910)
▶ Locke, John (1632–1704)
▶ Memory Codes
▶ Memory Consolidation and Reconsolidation
▶ Memory Persistence
▶ Motor Learning
▶ Motor Schema(s)
▶ Recall and the Effect of Repetition on Recall

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Memory for "What," "Where," and "When" Information in Animals

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Synonyms

Episodic-like memory; Episodic memory; Event memory; Object memory; Spatial memory; Temporal memory

Definition

The term "what-where-when memory" has been used to describe the ability of animals to integrate object, spatial, and temporal information from past episodes in memory. It has often been used interchangeably with the terms "episodic memory" or the more conservative "episodic-like memory" to describe the ability of nonhuman animals to remember components of trial-unique events. This ability has been qualified as episodic-*like* because the definition of episodic memory (as outlined in the human memory literature and elsewhere in this volume) involves not only the integration of what, where, and when information in memory, but it also involves a subjective, conscious experience (autonoetic consciousness or mental time-travel) upon retrieval. Therefore, both episodic-like memory and what-where-when memory have been proposed to describe the unique situation of nonhuman species that demonstrate behavioral evidence of this memory system, while still maintaining the traditional definition of episodic memory and its emphasis on a subjective conscious experience.

Theoretical Background

The distinction between memories for personally experienced past events and memory for factual knowledge about the world was first noted by Tulving (1983) who proposed that long-term memory was composed of two subsystems; an episodic memory system and a semantic memory system. Tulving argued that the episodic memory system allowed for the encoding of past episodes through the binding of various components of the event in memory (most notably, spatial and temporal information concerning the event). Furthermore, this system was characterized as involving a subjective conscious experience because when episodic memories are retrieved they are frequently accompanied by the feeling that one is reexperiencing the unique spatiotemporal context of the event. This subjective and phenomenological quality initially made episodic memory difficult to assess in nonhuman animals that are unable to convey information about their mental states through language. However, in recent years many researchers have developed behavioral tests that do not rely on verbal reports, and can be used to assess memory for past events in animals.

Important Scientific Research and Open Questions

A variety of different methodologies have been developed to examine event memory in animals (Crystal 2009); some approaches have focused on designing tasks that incorporate the natural food-caching or foraging behavior of the species being studied (e.g., Clayton et al. 2001), whereas others have used test paradigms from the study of memory with humans (e.g., Washburn et al. 2007). In these foraging-type tests, an animal finds different food sources at specific locations within the environment. They are then removed from the environment and allowed to return after varying delays. By setting up various contingencies regarding the perishability of different food sources over time, the experimenters are able to infer whether the animal remembers what, where, and when information from the past event by examining which locations they visit when reintroduced into the environment after a particular delay. Studies using this approach have shown that scrub jays and rats are capable of encoding what, where, and when information about trial-unique past events (for a comprehensive review, see Dere et al. 2006).

Another approach has been to design computerized tasks that can be used across species to examine what-where-when memory integration. In this paradigm, organisms manipulate a joystick, touchscreen, or other input device to respond to computer-graphic stimuli in accordance with the rules of these game-like tasks. An initial approach in this tradition used an analog of the popular children's memory game in which an array of cards are placed picture-side-down on a table. Pairs of cards are overturned to reveal the images on each. If the images match, the pair is removed from the array. If the images are different, the cards are returned to the face-down position. Thus, efficient responding requires memory for what is located where in this particular game, versus previous games where the same pictures might have been located elsewhere. Rhesus monkeys (*Macaca mulatta*), like humans, were able to retain information for multiple objects and spatial locations (e.g., Washburn et al. 2007). The monkeys perseverated on incorrect choices in this task and showed little evidence of integrating spatial and object information in memory. However, when the monkeys were presented with a computerized delayed matching-to-sample task that had been used successfully with pigeons, they were able successfully to report what, where, and when information from past episodes (Hoffman et al. 2009). It remains an open question whether these results reflect an integrated memory system that retains what, where, and when episodic information, or (as Skov-Rackette et al. 2006, reported for pigeons) the contributions of three complementary memory systems that work independently.

The opportunity to test memory for what-where-when in great apes that have been trained to report various components of past events through the use of symbolic lexigrams and photos (e.g., Menzel 2005; Schwartz et al. 2005) provides a methodological bridge between naturalistic, foraging-type tests and laboratory paradigms that are used to study episodic memory in humans. For example, Menzel developed a unique procedure for testing the what-where-when memory of a language-trained chimpanzee (*Pan Troglodytes*) named Panzee. Under Panzee's watchful eye, Menzel hid food items in the woods outside the ape's outdoor enclosure. For instance, he might conceal a peach in a container, buried in the ground well outside the cage. Hours or even days later, Panzee could recruit a caretaker (who was not aware what, where, or even whether something had been hidden) and use her lexigram keyboard to name the object that had been hidden. Then Panzee would direct the caretaker outdoors and to the location where the item was hidden, using pointing, posture, and vocalization to guide the caretaker's movements. Not only was Panzee almost perfect in recalling what had been hidden, she showed impressive skill in recall of where the item or multiple items were concealed, and did not make errors that reflected confusions across the different to-be-remembered locations.

Taken together, these studies have shown that a variety of species (including rats, pigeons, scrub jays, rhesus monkeys, and great apes) are capable of remembering multiple components of past episodes and are able to convey this information through their behavior. What remains unsettled is the degree to which these behaviors reflect an integrated episodic memory system analogous to the one that has been demonstrated in humans, accompanied by the experience of reliving the past. There is some suggestion that language facilitates the integration of what, where, and when memory by nonhuman animals. Menzel's (2005) demonstration of accurate episodic recall by a language-trained chimpanzee provides some evidence on this point, as does the Washburn et al. (2007) finding that rhesus monkeys, which had not been trained to represent information with a language-like symbol system, seemed to remember *what*, *where* and *when*, but not *what-was-where-and-when*. On this same point, language-trained chimpanzees perfomed significantly better than the monkeys on the memory game, and memory by humans was reliably compromised when they were not able to use language to encode the to-be-remembered information (Washburn et al. 2007).

Cross-References

► Episodic Learning
► Episodic-Like Memory in Food-Caching Birds

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Memory for Changes in Pictures and Displays

► List Memory and Change-Detection Memory in Animals

Memory for Serially Presented Lists

► List Memory and Change-Detection Memory in Animals

Memory Loss

► Semantic Memory in Profound Amnesia

Memory Modification

► Dynamics of Memory: Context-Dependent Updating

Memory of the Future

► Prospective and Retrospective Learning in Mild Alzheimer's Disease

Memory Persistence

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Synonyms

Long-term memory; Persistent memory; Retentiveness; Temporal extension of memories

Theoretical Background

In the first 2–6 h after acquisition, learned information can be consolidated into long-term memories (LTMs) (McGaugh 2000; Izquierdo et al. 2006). This process is now known as cellular consolidation and takes place mainly in the hippocampus. During this process, LTMs are labile and the acquired information is available through short-term memory (STM) systems, which operate in parallel to consolidation (Izquierdo et al. 1998). Once consolidated, LTMs may last for just a few days or for several weeks, months, or years. Persistence depends in part on the degree of emotional arousal present at the time of consolidation (McGaugh 2000). It is well-known that memories involving a higher degree of emotional arousal are retained longer (we all remember where we were and whom we were with at the time of the assassination of President Kennedy or the 9/11 attack, but not the day before or a week ago). But many memories with no important emotional content can also be remembered for a long time, like the Pythagoras theorem or Ohm's Law we learned in high school.

The research to be briefly described here refers to important molecular mechanisms of memory processing. These involve: (a) enzyme chains that convey signals to the nucleus of the neurons in order to trigger the involvement of transcription factors that signal the DNA to produce messenger RNAs that will then translate into specific proteins; the major such signaling pathways are the one triggered by cyclic adenosine monophosphate (cAMP) or protein kinase A (PKA) pathway, the one regulated by extracellular factors (extracellularly regulated kinases or ERKs), and the one regulated by Ca^{2+} and calmodulin; (b) nuclear proteins that act as transcription factors, of which the most important are CREB (cAMP response element binding protein) that is activated by the signaling pathways mentioned above, and the inducible factor c-Fos; (c) the brain-derived neurotrophic factor (BDNF) that is produced by neurons and causes growth of recently stimulated synapses; (d) the neurotransmitter, dopamine, and its receptor, D1.

Important Scientific Research and Open Questions

Recently, two different mechanisms based on the hippocampus have been found to regulate the persistence of LTMs beyond a few days. One involves the circadian activation of the ERK and the cAMP signal transduction pathways (Eckel-Mahan et al. 2008). Both signaling pathways are known to regulate memory processes through the phosphorylation of the transcription factor CREB (Izquierdo et al. 2006). The nadir of their activation cycle corresponds with severe deficits in hippocampus-dependent fear conditioning under both light–dark and free-running conditions, so this is probably unrelated to sleep cycles. The circadian oscillations in cAMP and MAPK activity are absent in memory-deficient transgenic mice lacking Ca^{2+} – stimulated adenylyl cyclases. Furthermore, physiological and pharmacological interference with oscillations in ERK phosphorylation after the cellular memory consolidation period impairs the persistence of hippocampus-dependent memory. The data suggest that the persistence of long-term memories may depend on reactivation of the cAMP/MAPK/CREB transcriptional pathway in the hippocampus during the circadian cycle.

The other mechanism involves the activation of dopaminergic cells in the ventral tegmental area both immediately and again 12 h after memory acquisition, again independently of sleep cycles (Rossato et al.

2009). These cells project to dopamine D1 receptors in the CA1 region of the hippocampus (Lissman and Grace 2005) and trigger the production of brain-derived neurotrophic factor (BDNF) 12 h posttraining in this area. Hippocampal BDNF production at this time, acting through MAPK activation and the production of various transcription factor triggered by early genes, prolongs memory persistence for several weeks (Bekinschtein et al. 2007, 2008). Probably this is due to the well-known trophic effects of BDNF on synapses (see Bekinschtein et al. 2008a, b). It additionally involves the production of several synaptic proteins after training in the hippocampus (Bekinschtein et al. 2010) triggered by c-Fos produced 12 h before (Katche et al. 2010).

Evidence suggests that this dopamine-regulated hippocampal BDNF/c-Fos mechanism exists in humans and works better up to around the age of 40 (Izquierdo et al. 2008). Healthy human volunteers under that age recall more details about declarative memories acquired 7 days before than those over 40. The deficit can be overcome by the double-blind ingestion of a dopamine-enhancing treatment given 12 h after the acquisition of that memory. The relative decline of persistence seen after middle age has also been described in rodents (Gold and McGaugh 1975).

Open Question

It remains to be seen whether these two systems that regulate memory persistence beyond the first couple of days are independent from each other or operate separately. Clearly, both function in the absence of retrieval and thus seem to be unrelated o reconsolidation.

Cross-References

▶ A Stability Bias in Human Memory
▶ Adaptive Memory and Learning
▶ Attention, Memory and Meditation
▶ Auto-associative Memory and Learning
▶ Capacity Limitations of Memory and Learning
▶ Dreaming: Memory Consolidation and Learning
▶ Memory Codes
▶ Memory Consolidation and Reconsolidation
▶ Memory Dynamics
▶ Sensory Memory (Iconic and Echoic Memories)
▶ Short-Term Memory and Learning
▶ Working Memory and Information Processing

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Memory Reconsolidation

▶ Dynamics of Memory: Context-Dependent Updating

Memory Recovery

► Retrieval Cues and Learning

Memory Retrieval Cues

► Retrieval Cues and Learning

Memory Span

The number of items that people can immediately recall following a sequence of items.

Memory Storage

► Memory Consolidation and Reconsolidation

Memory Trade-Off

A phenomenon described by some researchers, in which memory for some central emotional item is enhanced (for example, a the gun pointed at you), but that enhancement comes at a decrement in memory for other information in the episode (for example, the face of the person pointing the gun at you).

Memory-Enhancing Strategies

► Mnemonic Learning
► Mnemotechnics and Learning

Memristor

A memristor is a passive electronic component, like resistors, coils, and capacitances. In 1971, Chua postulated its existence based on theoretical arguments. Recently, memristors have been realized in hardware on a thin film of titanium dioxide.

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Mental Abstraction

► Abstraction in Mathematics Learning

Mental Activities of Learning

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Synonyms

Mental processes of learning

Definition

Mental processes of learning are the processes which enable and constitute human learning and support it on the one hand, i.e., the processes which are used by a human being to learn to acquire this or that competency (understanding and conceptualizing a problem situation, working out a general and specific hypothesis on how to solve the problem, controlling and correcting the problem solving process, etc.), and the mental activities which are considered to be the results of learning on the other hand.

Theoretical Background

Recent developments have effected major changes in traditional theories of learning and instruction, such as the Instructional Design movement. There has been a fundamental reorientation from the behaviorist to the cognitivist and constructivist paradigm: Increased emphasis has been placed on the active and constructive nature of the learner's performance, on meaningfulness as an important condition of learning productivity, and on the guiding and determining role of internal (vs. external, behavioral) components of learning processes such as cognitive and metacognitive strategies, mental schemata, etc. Mental activities of learning can be considered from at least two possible angles: (1) *structure* – the aspect of the *learning task* one or another mental activity is directed to and what a role it plays, and (2) *function* – the features of mental activities which precede, accompany, or follow learning. With regard to the former, starting with the classical studies by N. Ach, W. Koehler, and K. Dunker theorists have cited a more or less stable list of such tasks and activities directed to solving them (with various amounts of detail and different emphasis depending on the theoretical standpoint of the scholar): facing the problem and its realization, analysis of the problem situation, conceptualization of a plan to solve the problem or/and a path to reach a goal, and comparison of intended result and that actually reached through research. The most detailed list is presented in Galperin's description of the structure of the so-called orientation base of action, i.e., 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 to reach a solution in a problem situation. These components represent the subjective and objective characteristics of a problem situation and include the following: (1) representation of the final product of an action, (2) representation of intermediate products, (3) representation of a general plan for achieving the final product, (4) representation of plans for achieving the intermediate products, (5) representation of the tools necessary for achieving these products (both orientation & execution tools), (6) representation of the plan and tools for control and correction of actions as they are being executed, and (7) representation of the entire structure of a complete orientation base of action (Galperin 1992).

The *functional* aspect highlights the features of mental activities preceding, accompanying, or following learning and describes how these features influence the qualitative and quantitative results of learning. It is not enough to report on the *content* of mental activities, i.e., about *what* is guiding the learning process; information about *how* this occurs is not less important. Another contribution by P. Galperin – *primary and secondary properties of mental actions* – provides a good example of the functional description of mental activities of learning (see also the ► Internalization entry in this volume).

Important Scientific Research and Open Questions

There are several important issues that both represent prospective research areas and raise pertinent and currently unanswered questions.

1. Using the adjective "mental" (e.g., "mental efforts," "mental schemata," "mental activity," "mental models," etc.) to explore human learning involves distinguishing between two essentially different mechanisms that may cause a lack or even a complete absence of "mentalability" (capacity to act in a mental plan) in one or another case: (a) macro-genetically, a child's mental plan may be underdeveloped (Piaget 1970; Galperin 1982) and hence lead to his/her inability to act mentally in definite spheres of reality; (b) micro-genetically, concrete mental actions, which are the prerequisites for learning designed content, might not be formed at all (or might be formed with inappropriate and insufficient properties: under- or ungeneralized, under- or untransferrable, etc.) in a student's past (Galperin 1992).
2. When speaking about "developmental dimensions" of learning research, one has to distinguish between two different standpoints. First, developmental dimensions should be considered as an essential and necessary part of the learning studies knowledge base. This means taking into account the following: (a) how to plan, design, and organize learning/teaching processes in accordance with macro-as well as micro-developmental regularities; (b) the short- and long-term developmental consequences of these processes, i.e., the extent to which the learning/teaching processes influence (or perhaps even determine) a student's cognitive, personal, moral, social, and emotional development. Second, developmental dimensions should be considered as direct and

immediate goals of the learning/teaching processes. L. Vygotsky (1978) formulated this goal as follows: "Instruction is good only when it proceeds ahead of development." This goal was approached and reached with much more concrete psychological descriptions and instructional prescriptions in a number of works by P. Galperin (Galperin 1982, 1992 a.o.).

3. *Three* psychologically different but interconnected *levels of orientation base* may be distinguished in considering mental activities of learning: (a) the *executive orientation base*, a scheme of human orientation on *how to do* something; (b) the *goal-orientation base*, a scheme of human orientation on *what to do*;(c) the *sense orientation base*, a scheme of human orientation on *why* (*for what*) *to do* something. The three levels of orientation base are connected to each other in both ascending and descending order: Human understanding on how to do something also affects higher level sense and goal representations and is in turn affected by the possibilities and execution of the sense and goal-orientation bases (Podolskij 1997).
4. A number of recent publications suggest expanding the cognitive field of the learning studies knowledge base by including such elements of human mental life as feelings, values, and motives. These components of human activity do play an important, sometimes even a determining role in learning processes. The potential of a learning environment would certainly increase if one "switched on" these variables to work in favor of learning and teaching processes. The problem is how one should interpret these variables in terms of modern learning studies and link them rationally and not only intentionally with the "traditional" ones. Thus, the first question is whether the mental activities of learning are limited by cognitive processes only.
5. How wide and deep should mental activities of learning and, accordingly, an expected result of a learning/teaching process be? For instance, learning of arithmetic operations in elementary school may be initiated by a quite concrete objective to teach the children to count. At the same time, this process may also be considered within the framework of the acquisition of fundamental mathematical concepts or even within the context of age-related developmental transitions. It has been shown that the acquisition of a set of basic initial concepts such as "measure," "unit," and "number" facilitates and accelerates the transition from the pre-operational to the concrete operational level of intellectual development in preschool children (Davydov 1999). Thus the question is what should be learned: concrete knowledge, more general cognitive skill, or even metacognitive strategies and heuristics?

Cross-References

► Activity Theories of Learning
► Development and Learning
► History of the Sciences of Learning
► Internalization
► Learning Activity
► Mental Model
► Mental Representation
► Piaget's Learning Theory
► Zone of Proximal Development

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Mental Aging

► Cognitive Aging

Mental Arithmetic

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Synonyms

Mental calculation

Definition

Mental calculation is the practice of doing mathematical calculations in the mind without any help from computing devices or writing them down.

Theoretical Background

The Traditional View

Mental calculation or arithmetic is traditionally defined as doing exact calculations in one's head, with no help from any external tool such as paper and pencil, a mechanical or electronic calculator, a computer, etc. According to this traditional view, mental arithmetic is different from various other ways of determining outcomes of calculations, including computational estimation (which is not exact), written computation (which uses paper and pencil), and working with computational devices.

In this view, mental arithmetic typically involves the use of specific strategies that are devised for specific problem types. These strategies are then taught and trained in the educational setting in a routine way: students are learned to always use a particular strategy on a particular problem type. For example, to calculate the difference between two numbers a and b, when the digits of b are all smaller than the corresponding digits of a, the calculation can be done easily mentally digit by digit, for example, solving $472 - 241$ simply by subtracting 2 from 4 in the hundreds place, 4 from 7 in the tens place, and 1 from 2 in the units place, and finally by putting together the different partial outcomes from left to right: 231.When the above situation does not apply, various other ways of determining the difference are possible. To calculate $452 - 72$, one can turn the problem into $452 - 52 - 20 = 400 - 20 = 380$. In some cases, particularly when the difference between the two given numbers is very small or if several digits from b are larger than their corresponding digits in a, it may be easier to find how much must be added to b to get a, as in the following example of a subtraction-by-addition strategy: To calculate $802 - 795$, one can add 5 to 795 (resulting in 800), then add 2 (to get 802), and then add the two added numbers 5 and 2 to arrive at the final answer 7. Likewise, to multiply a number by 5 by means of mental arithmetic, children learn first multiply that number by 10, and then divide it by 2. Or, to multiply by 9, they learn to multiply the number by 10 and then subtract the original number from this result. For example, $9 \times 32 = 320 - 32 = 288$.

People may decide to solve problems mentally (a) when it is more efficient (i.e., faster and/or more accurate) than other means of calculation (e.g., when the numbers in the computational problem do not necessitate to rely on any kind of external tool), (b) when the external tools that would facilitate computation are not available or usable, or (c) when those tools are not allowed (as in a mental arithmetic class or test). In this traditional view, mental arithmetic is taught in school primarily because it is practically helpful, but also because it contributes to the development of attention, (long-term) memory, and visualization skills.

An Alternative View

Many researchers in mathematics education adhere a different view on what mental arithmetic is and why it should be taught in school, by stating that its quintessence is not that it is done *in* the head (versus being done on paper or on a machine), but *with* the head (versus in a mechanical way) (Van den Heuvel 2001). So, rather than describing mental arithmetic as arithmetic that is done purely mentally without external representations or aids, they capitalize on the nature of the computational processes. According to this

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alternative view, mental arithmetic is characterized by three important features: (a) in mental arithmetic one operates on numbers rather than on digits, (b) these operations on numbers are – ideally – done with understanding of the underlying mathematical principles and relations, and (c) these operations are executed by creatively and flexibly taking into account certain characteristics of the numbers involved in the problem. These features of mental arithmetic are typically absent in doing the algorithms of written computation, which (a) does not demand that one understand what the digits represent, (b) tends to mask the underlying principles that make the algorithm work, and (c) does not require any creativity from the solver but involves a strict adherence to the taught algorithmic procedure algorithm. According to this mathematics education point of view, mental arithmetic does not exclude the use of paper and pencil for writing down partial outcomes; however, doing a computation in one's head by following the standard algorithm would not be considered as mental arithmetic.

Important Scientific Research and Open Questions

Research based on this alternative conception of mental arithmetic revealed, first, a rich variety of mental arithmetic strategies. These strategies can be generally classified into three categories:

- *Jump* (or sequential) strategies in which the numbers are seen primarily as objects in the counting row and for which the operations are movements along the counting row: further (+), back (−), repeatedly further (×), or repeatedly back (÷). For instance, solving 54 + 37 by doing 54 + 30 = 84, 84 + 6 = 90, and 90 + 1 = 91.
- *Split* (or decomposition) strategies in which the numbers are seen primarily as objects with a decimal structure and in which operations are performed by splitting and processing the numbers on the basis of this structure. For instance, solving 54 + 37 by doing 50 + 30 = 80 and 4 + 7 = 11 and then adding the two partial sums: 80 + 11 = 91.
- *Varying* (or compensation) strategies based on other arithmetic properties in which the numbers are seen as objects that can be structured in all sorts of ways and in which operations take place by exploiting a suitable structure and using the appropriate arithmetic properties (Buys 2001).The prototypical example of this latter kind of strategy is the story of the great mathematician Gauss as a child, who, asked to find the sum of 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10, produced the answer extremely quickly, because he noticed that the numbers could be arranged in pairs 1 + 10, 2 + 9, etc., of which there are five, all adding to 11, hence the total is 5 × 11 = 55.

These three types of strategies can, for each of the four arithmetic operations, be performed at different levels of internalization, abbreviation, abstraction, and formalization (e.g., at a lower level by using external representations, such as the base-ten blocks or a number line, at a higher level by noting intermediate steps in formal-arithmetic language, or purely internally) (Verschaffel et al. 2006, 2007).

Second, although research has indicated that certain problems and problem contexts elicit the use of mental arithmetic, there is at the same time evidence that mathematics learners apply these mental strategies less frequently, less efficiently, and less flexibly than advocates of this alternative view would like to see. In their opinion, this disappointing finding is a direct result of the traditional approach to mathematics education, with its strong emphasis on the teaching and practice of the standard algorithms for written computation (Van den Heuvel 2001; Verschaffel et al. 2006, 2007).

Third, although most mental arithmetic strategies that people apply have been more or less explicitly taught, research has also revealed that efficient mental strategies are sometimes discovered by the learners themselves. This holds, clearly, for Gauss' efficient strategy for adding long series of adjacent numbers, but also for the above-mentioned subtraction-by-addition strategy, which some learners reportedly have discovered themselves. In this respect, we also refer to a specific research line which focuses on so-called arithmetical savants or people who have outstanding computational skills (compared to their moderate or even weak skills in other domains, even intelligence) and who can do mental calculations that are impressive in accuracy, speed, and extent of computation (Heavey 2003). Research on these arithmetical savants has revealed that their unusual proficiency is subserved by a variety of strategies – frequently invented ones – ranging from counting and grouping, to direct retrieval from memory of numerical facts, and use of mathematical shortcuts and rules.

Fourth, strategies for mental arithmetic typically require good conceptual understanding of the underlying structures and principles. Indeed, to meaningfully and flexibly apply mental arithmetic procedures, the more or less explicit use of conceptual understanding of the decimal numeral system and/or of operation-related principles such as commutativity ($a + b = b + a$), associativity ($a + b - c = b - c + a$), and inversion ($a - b = c$, so $c + b = a$) are required (Rittle-Johnson and Siegler 1998). However, the precise role of this conceptual knowledge in the development of mental arithmetic – whether it precedes to, results from, or co-develops with procedural skills – is still a matter of debate among researchers.

Educational Issues

Because mental arithmetic is conceptualized primarily as a way to develop (a) a sense of structure in numerical and mathematical relations, (b) a rich repertoire of solution strategies, and (c) a disposition to exploit such structure to simplify a mathematical task where possible, it should be taught and practiced both *before* children start learning the written algorithms for the basic operations and *alongside* that part of the mathematics curriculum. Moreover, mental arithmetic can be used as a "stepstone" to written algorithm. In many current curricula and textbooks, the written algorithms are gradually built out of children's strategies for doing mental arithmetic. This process of "progressive schematization" (Van den Heuvel 2001), whereby the available mental arithmetic strategies that are available in children's strategy repertoire are gradually internalized, shortened, and schematized until the algorithm is somehow "discovered" is one of the main features of the so-called realistic mathematics education approach. However, not all mathematics educators support this instructional approach to the written algorithms.

Another hotly debated issue among mathematics educators is whether the algorithmic methods still need to be mastered by all children, and (thus) deserve so much instructional attention. With the easy access and omnipresence of electronic computational devices, the idea that teaching students for long periods on solving problems involving large numbers by means of these written algorithms seems to be more appropriate to the twentieth century than the twenty-first is gaining ground. In some Western countries, such as the USA, the UK, and the Netherlands, curriculum reform documents have been proposed and introduced wherein much less attention is paid to the algorithms for written computation and much more attention to mental arithmetic and computational estimation. But, internationally, most elementary school mathematics curricula continue to pay, for mixed reasons, considerable attention to the teaching and learning of these algorithms.

Cross-References

► Adaptability and Learning
► Flexibility in Problem Solving: Analysis and Improvement
► Mathematical Learning
► Problem Solving

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Mental Calculation

► Mental Arithmetic

Mental Chronometry

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Synonyms

Cognitive processing speed; Reaction time

Definition

Mental chronometry is the scientific study of cognitive processing speed. Processing speed is measured by reaction time (RT), which is the elapsed time between the onset of a stimulus (e.g., visual or auditory) and an individual's response. The elementary cognitive tasks (ECTs) used in mental chronometric research are typically very simple, requiring a relatively small number of mental processes or operations and eliciting RT's that are measured in milliseconds (ms). Mental chronometry has been used extensively by experimental and differential psychologists to examine models of information processing (e.g., stages of processing, serial versus parallel processing) as well as individual differences in human cognitive abilities.

Theoretical Background

The systematic study of RT began with the work of the Prussian astronomer F. W. Bessell (1784–1846). He discovered reliable differences between individuals in their ability to accurately record the time a given star crossed the hairline in a telescope. He developed the *personal equation* to correct for differences in simple reaction time (SRT, reaction time for a single response to a single stimulus) between observers. Use of the personal equation led to improvements in the precision of measurement in astronomy. Although Sigmund Exner (1846–1926) was the first to use the term *reaction time*, the Dutch physiologist Frans C. Donders (1818–1889) is regarded as the first mental chronometric researcher. Donders extended the measurement of SRT to include experimental conditions in which there were multiple response stimuli, alternatives, or both. The more complex *choice reaction time* (CRT) and *discrimination reaction time* (DRT) tasks involved all the sensory and motor components in SRT, but with the added mental processes involved in choosing between two or more different stimuli. Donders developed the *subtraction method* to decompose total RT on these more complex ECTs into separate stages of processing, such as perceptual discrimination time (DRT – SRT) and response selection time (CRT – DRT). Donders' *subtraction method* was eventually disputed, but not before experimental research on RT became a prominent focus of the world's first psychological laboratory in Leipzig, founded by Wilhelm Wundt (1832–1920), and the basis of much subsequent research in mental chronometry. During this period, Sir Francis Galton (1822–1911) developed a diverse battery of RT and perceptual-motor tasks to measure sensory discrimination and speed of response to external stimulation, which he hypothesized was related to general mental ability, or psychometric *g*. Galton's work was overshadowed by the success of Alfred Binet's (1857–1911) test of intelligence, published in 1905. As a result, interest in mental chronometry by differential psychologists waned throughout much of the twentieth century before being revived by Arthur Jensen and others in the 1980s (see Jensen 2006).

Important Scientific Research and Open Questions

Over the past 30 years, some of the most important work in the field of intelligence has involved the use of mental chronometry. As contemporary research on the nature of intelligence, or psychometric *g*, has begun to move from descriptive to causal analysis, researchers have attempted to identify variables related to intelligence outside the realm of psychometric tests, such as the average evoked potential, the electroencephalogram, glucose metabolism in the brain as expressed by PET scan, and RT on ECTs. In recent years, the theory that individual differences in intelligence are integrally related to speed and efficiency of cognitive processing has received increased attention (see Jensen 1998). This theory is based upon basic principles of cognitive psychology, the most basic of which is the limited capacity of short-term memory (STM). This refers to the restriction of information from the perceptual system and of information retrieved from long-term memory (LTM) that can be simultaneously processed. In addition to limited capacity, information in STM rapidly decays without continuous rehearsal or is lost as a result of interference. In order to compensate for limited capacity, rapid decay, and interference, one must either continually process information in STM or store it in LTM. But the storage process itself takes time and channel capacity, so there is a trade-off between the amount of information that can be stored and processed at one time. The advantage of speed of processing increases with information requiring greater complexity of mental processes. More operations (such as encoding, chunking, transformation, and storage of incoming information in LTM) per unit of time can be performed prior to information decay and without overloading the information processing system. Therefore, higher intelligence should be related to faster and more efficient speed of cognitive processing.

Many different ECTs have been used to investigate the relationship between speed of information processing and intelligence. Chronometric techniques have been used to discover highly reliable individual differences in a variety of ECTs. The response accuracy on ECTs, however, is typically so high (errors averaging less than 5% of all responses) that the only reliable measure of individual differences is RT. The ECTs with the highest correlation with intelligence generally have average RTs of less than 1 s. In addition, not only are the skills and processes required for successful task completion possessed by virtually every subject prior to participation, even among individuals with intellectual disabilities, but the content of these ECTs hardly resembles that of conventional psychometric tests. Many ECTs have no symbolic content, requiring subjects simply to push buttons that light up. Those ECTs that do employ digits, letters, or familiar words are so simple that most subjects would score 100% correct responses if they were tested under unspeeded conditions. These observations suggest that ECTs are measures of basic processes, or at least a small number of processes. The following is a brief discussion of some of the most widely used ECTs that have been used in the study of intelligence.

Hick Paradigm. The Hick paradigm, named after Hick's Law (1952), measures both simple and choice RT. Hick's Law states that RT increases linearly as a function of the logarithm of the number of choice alternatives (n), usually scaled in bits (i.e., $\log_2 n$, or the amount of information needed to reduce stimulus uncertainty by half). The *intercept* of the regression of RT on bits reflects sensory and muscle lag, apprehension and encoding of the stimulus, and response production. The *slope*, on the other hand, reflects central cognitive processes and is a measure of the speed of information processing expressed as ms per bit. Individual differences in RT, as well as the slope of the regression of RT on stimulus set-size scaled in bits, are significantly correlated (negatively) with intelligence so that the RT-intelligence correlation increases linearly as a negative function of stimulus set-size scaled in bits. Another theoretically interesting finding is that intra-individual variability of RT (the standard deviation of RT over trials) in the Hick paradigm is often more highly correlated with intelligence than the overall mean or median RT.

Memory Search Paradigm. The memory search (MS) paradigm measures the speed of scanning information in STM. In contrast to the Hick paradigm, where RT increases as a function of bits, RT in the MS paradigm increases as a linear function of the number of items scanned in STM (Sternberg 1966). In the MS paradigm, the intercept of the regression of RT on set-size reflects stimulus encoding, comparison of the probe item to those held in STM, a binary decision, and response production. In contrast, the slope is a measure of scanning speed, expressed as ms per item scanned. Both the intercept and slope of the regression of RT on set-size have been shown to be related to intelligence.

Visual Search Paradigm. This paradigm, introduced by Neisser (1967), is a measure of the speed of visual search (VS). Essentially the inverse of the MS paradigm, the VS paradigm reduces the role of STM to a minimum. In the VS paradigm, RT increases as a linear function of the number of items scanned in the stimulus array. In the VS paradigm, the intercept of the regression of RT on set-size reflects only the binary decision and response production. The slope, however, measures the speed of encoding a single stimulus and making a single binary comparison, expressed as ms per item searched. Both the intercept and slope of the regression of RT on set-size have been shown to be related to intelligence.

Posner Paradigm. This paradigm stems from the work of Posner and his colleagues (Posner 1978). Two separate ECTs are used in this paradigm to provide a measure of the speed of retrieval of over-learned information from long-term memory (LTM). The first, Physical-Match, involves stimulus encoding, comparison of the physical features of the stimulus, a binary decision, and response selection. The second, Name-Match, involves stimulus encoding, comparison of the semantic features of the stimulus, a binary decision, and response selection. Name-Match RT is significantly longer than Physical-Match RT. Significant differences have also been found between subjects of high and low verbal ability, and RT in a modified version of the Posner paradigm has been found to significantly correlate (negatively) with intelligence.

Inspection Time. Although research on inspection time (IT) has been traced to James McKeen Cattell in the 1880s, contemporary interest in IT stems from the work of Vickers, Nettelbeck and their colleagues (e.g., Vickers et al. 1972). IT, the only index of mental speed that does not involve either motor (output) components or executive cognitive processes (meta-processes), is held to tap individual differences in the "speed of apprehension," the quickness of the brain to react to external stimuli prior to any conscious thought. Meta-analysis results suggest that IT is correlated at approximately −.54.

In sum, many different ECTs, ostensibly tapping different stages of processing (such as encoding, STM scanning, and LTM retrieval) have been used to investigate the relationship between RT and intelligence. Each of the ECTs discussed has been found to have modest, but reliable (negative) correlations with intelligence, typically in the range of −.30 to −.50. The correlation between these ECTs and intelligence may, in fact, be somewhat higher after correction for the attenuating effects of restriction of range and measurement error. Multiple correlations between intelligence and various measures of RT are approximately .60. Jensen (2006) convincingly argued that further advances in mental chronometry will depend in large part upon standardization of chronometric apparatus and testing procedures to eliminate the potentially confounding effects of method variance.

Cross-References

- ► Human Cognition and Learning
- ► Human Cognitive Architecture
- ► Intelligence, Learning and Neural Plasticity
- ► Memory Persistence
- ► Working Memory

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Mental Efficiency

► Cognitive Efficiency

Mental Effort

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Synonyms

Cognitive efficiency; Cognitive load; Mental load

Definition

The number of non-automatic elaborations applied to a unit of material to be learned (Salomon 1984, p. 648).

Theoretical Background

What Mental Effort Is

Mental effort was first used as a concept to help determine how hard a person tries to actively process presented information. It was seen as a combination of perceived demand characteristics, perceived self-efficacy, and level/depth of information processing such that the first two influence the last which determines the amount of invested mental effort. *Perceived demand characteristics* depend upon the degree to which a source (e.g., a stimulus, task, context) that is being attended to poses demands on ones's processing, because information has to be extracted, discriminated among, remembered, and elaborated upon (Salomon 1984). Research has shown that if the source is seen by a person as being complex (e.g., if a person is a complete novice) and/or if the learner is told that the content of the presented material will be tested, then the perceived demand will be high. If a person perceived the source as being simple (e.g., he/she is more of an expert in the area) and/or is told just to enjoy the materials, then the perceived demand will be low. *Perceived self-efficacy* (Bandura 1982) relates to how efficacious a person is; the extent that one believes that he/she is capable of performing in a specific manner to attain specific goals. According to Bandura, the more efficacious learners perceive themselves to be, the more likely they are to invest sustained effort to carry out a task. In this respect it is related to persistence and motivation (F. Kirschner et al. 2011). Finally, *depth of processing* (Craik and Lockhart 1972) relates to the degree to which a person encodes/recodes a source. The idea is that the more one elaborates meaning with already experienced associations, images, and stories, the more likely one is to remember something. To this end, encoding/recoding of studied materials for semantic meaning is seen as deeper processing and requires more mental elaborations than encoding/recoding for orthographic features. Put together, the *amount of invested mental effort* was defined by Salomon as "the number of non-automatic elaborations applied to a unit of material" (Salomon 1984, p. 648) that a person invests which is determined by her/his feelings of self-efficacy, how the task is perceived which, in turn, determines how deeply the information will be processed. In this way remembering simple factual information is considered to require little mental effort while inferential learning requires more mental effort. Furthermore, in Salomon's terms, learning from "easy media" such as when watching television requires little mental effort – leading to more surface level learning – while learning from "tough media" such as learning from reading books is seen as requiring more mental effort, with a concomitant increase in deeper learning.

From Mental Effort to Cognitive Load

As stated, mental effort was based upon cognitive, perceptual, and volitional factors. A term that has supplanted mental effort – though often used interchangeably with it is cognitive load (P. Kirschner 2002; Sweller 1988; see also Cognitive Load Theory in this Encyclopedia). Cognitive load is based upon human cognitive architecture which consists of a severely limited working memory with partly independent processing units for visual/spatial and auditory/verbal information, which interacts with a comparatively unlimited long-term memory. Paas et al. (2003) see, in this respect, mental effort as "the aspect of cognitive load that refers to the cognitive capacity that is actually allocated to accommodate the demands imposed by the task; thus, it can be considered to reflect the actual cognitive load" (p. 64). Cognitive load theory distinguishes between three types of cognitive load, dependent on the type of processing causing it, namely intrinsic load, extraneous load, and germane load which are additive in that, if learning is to occur, the total load of the three together cannot exceed the working memory resources available.

How Mental Effort Is Measured

To measure mental effort, a 9-point symmetrical category scale is often used (Paas and Van Merriënboer 1993). This scale is a subjective, indirect measure of cognitive load that asks learners to report the amount of mental effort that they invested in understanding learning materials ranging from "very, very, very little effort" to "very, very, very much effort."

What This Means

Knowing the mental effort that can and is invested when attending to a source is important in three ways. First, from the classical definition of mental effort (Salomon 1984) it can be used to mediate learning. By affecting the learner's perceived self-efficacy and/or by the learner's perception of the task characteristics, both depth of processing and amount of invested mental effort can be positively influenced.

Second, from the cognitive load perspective, it can be used to help design and develop better instruction. Instructional designs which increase extraneous load and which do not help and/or even hamper learning should be avoided while designs which reduce extraneous load (with or without a concomitant increase in germane load) should be embraced. Also, instructional designs that result in unused working memory capacity due to low extraneous load can be further improved by encouraging learners to engage in conscious cognitive processing directly relevant to learning. The greater the proportion of germane cognitive load created by the instructional design, the greater the potential for learning.

Finally, mental effort can be used to determine the instructional efficiency of learning materials which is useful for either comparing instructional designs or researching them. The combination of mental effort and performance allows the determination of instructional efficiency in that high-task performance associated with low effort is considered high instructional efficiency, whereas low-task performance with high effort is considered low-instructional efficiency (Paas and Van Merriënboer 1993; Van Gog and Paas 2008).

Important Scientific Research and Open Questions

Group Mental Effort

Although, contemporary thinking about learning – both initial and lifelong – has gravitated from individual learning toward learning in collaborative environments or situations, research in which group instead of individual mental effort is the focus of attention has not yet received much attention. Recently, group or collaborative learning has become recognized as an alternative way of overcoming individual WM limitations (F. Kirschner et al. 2009), in the sense that groups of collaborative learners can be considered as information-processing systems (Hinsz et al. 1997), consisting of multiple limited WMs which can create a collective working space. At this point in time it is not clear whether the same methodology used for determining mental effort in individuals can be reliably used for determining group mental effort.

Mental Effort During Task Performance

Mental effort measurements are normally collected during or after the learning phase and when related to the performance scores, they can provide an indication of the type of load imposed on the learner, the quality of the learning outcomes, and the quality of different instructional conditions (Paas and Van Merriënboer 1993; Van Gog and Paas 2008). In future studies it would be interesting to investigate how the measurement of mental effort before performing the task relates to the conventional measures taken during or after performing the task. Recently, this pre-mental effort rating has been used as an indicator of a learner's confidence in completing a task successfully instead of one of the more traditional measurements of self- or group-efficacy (F. Kirschner et al. 2011).

Cross-References

► AIME (Amount of Invested Mental Effort)
► Capacity Limitations of Memory and Learning
► Cognitive Load Measurement
► Cognitive Load Theory
► Cognitive Tasks and Learning
► Schema Development
► Self-Efficacy and Learning
► Short-Term Memory

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Mental Graphemic Representations

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Synonyms

Mental orthographic images; Mental orthographic representations; Sight word spellings; Visual orthographic images; Visual spellings; Word spellings

Definition

Mental graphemic representations (MGRs) are the stored mental images of written words in memory. These word-specific images can include complete and accurate images of written words (e.g., *cat*), less clear or incomplete images that contain only a few letters (e.g., *prsnl* for *personnel*), or word parts such as prefixes and suffixes (e.g., *re-*, *-ing* for *recycling*). As shown in (Fig. 1) below, the letters missing in an incomplete MGR often are those that are ambiguous and correspond to sounds that can be represented by more than one letter or letter combination. Well-established and complete MGRs are necessary for fluent reading and writing. When individuals can match printed words to previously stored MGRs, words are read effortlessly and fluently and comprehension is aided. Likewise, individuals who can call upon their MGRs when writing words spend less time considering how to spell and more time on conveying the intended message of the composition. Incomplete MGRs, as represented below, can lead to slower and incorrect guesses during reading and inaccurate, misrepresentative spellings See (Fig. 1). MGRs should not to be confused with orthographic pattern knowledge. Generally, orthographic pattern knowledge refers to an individual's knowledge of relationships between sounds and their corresponding spellings (e.g., the "k" sound can be represented in written English by a c, k, ck, and ch) and other spelling rules or patterns (e.g., long vowel sounds are typically represented by two vowel letters in English; double consonant letters can occur in the middle and end of English words, but not in the initial position).

Incomplete MGR	*p*	*r*	*s*		*n*		*l*
Correct spelling	*p*	*er*	*s*	*o*	*nn*	*e*	*l*
	↓	↓	↓	↓	↓	↓	↓
Possible spellings	*p*	*er*	*s*	*a*	*n*	*a*	*l*
		ir		*e*	*nn*	*e*	
		ur		*i*			
				o			
				u			

Mental Graphemic Representations. Fig. 1 Example of Incomplete Mental Graphemic Representation

Theoretical Background

There is a long history of discussion on MGRs; much of this dialog has focused on the role of MGRs in reading and how MGRs are acquired. One well-known model that accounts for the role of MGRs in reading is the dual-route (cascading) model of reading (DRC, Coltheart et al. 2001). This model posits that there are two main processing routes for reading. The first route is direct; word-specific orthographic information (an MGR) is accessed quickly when an indivdiual encounters a known written word while reading. This route often is referred to as sight-word reading. The other route in Coltheart et al.'s model is indirect; letters are matched to sounds and then blended to read words. This indirect route is a commonly referred to as decoding or word attack in the reading literature. The indirect route, as its name implies, requires an additional processing component (the transformation of letters to sounds) and thus is not associated with fluent reading. Conversly, the direct sight-reading route, within which clear MGRs are accessed, is associated with fluent reading.

For decades, theorists have proposed that children acquire MGRs as they phonologically recode novel words (i.e., take an indirect route to reading; see Ehri 1992; Share 1999). Ehri's amalgamation hypothesis and Share's self-teaching hypothesis both posit that as children decode, or sound out, words, the sounds are bonded to the letters of the words, creating a clear and "self-taught" image or MGR of the words. Thus, the ability to develop initial MGRs relies on children's phonemic (sound) awareness and knowledge of the alphabetic principle (letter-sound correspondence). Although multiple scientific reports have documented young children's MGR acquisition via phonological recoding, not all investigations have upheld the basic tenets of these two hypotheses. For example, some children demonstrate MGR acquisition without having basic phonological recoding abilities and other children who can phonologically recode words do not necessarily develop adequate MGRs.

Recently, other investigators have examined young children's ability to acquire initial MGRs implicitly, without overt phonological recoding of novel words (e.g., Apel 2010; Apel et al. 2006; Wolter and Apel 2010). In these latter studies, preschool and kindergarten children were exposed to novel words within shared storybook reading contexts and then required to spell and identify the novel words. Results across these studies suggest that young children can acquire initial MGRs after four exposures to novel words. This learning is affected by the phonological and orthographic regularities of spoken and written language. Further, children's ability to acquire initial MGRs is related to and predicts their concurrent reading and/or spelling skills beyond that predicted by their phonemic awareness skills. Children with identified language impairment or from lower socioeconomic homes are less facile in their implicit MGR learning abilities. Finally, the ability to implicitly develop initial MGRs is strongly associated with the ability to acquire initial phonological knowledge for the novel spoken words. These findings, together with results of previous investigations linking MGR development to phonological recoding abilities, suggest that young children acquire MGRs in both volitional and implicit learning contexts.

Important Scientific Research and Open Questions

That children acquire MGRs in both volitional and implicit (non-volitional) learning contexts has important implications for understanding reading and spelling development, identifying children at risk for literacy learning, and facilitating early literacy intervention. Several questions, however, remain to be answered before screening assessments and treatment options can be developed. First, to date, no investigation has simultaneously examined volitional and non-volitional MGR learning in the same children and whether the learning context affects the robustness of the MGRs. Second, although researchers have examined the concurrent relation between MGR learning and literacy skills, additional investigations of the predictive abilities of MGR acquistion for later literacy abilities are needed. Finally, initial MGR learning, like early spoken word learning, is influenced by the statistical regularities inherent in words. It remains to be determined when children become sensitive to orthographic statistical regularities, an apparent important prerequisite to acquiring initial MGRs.

Cross-References

- ► Anticipatory Schemas
- ► Abilities to Learn: Cognitive Abilities
- ► Development and Learning (Overview)
- ► Literacy and Learning
- ► Verbal Behavior and Learning

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Mental Health Disorder

► Achievement Deficits of Students with Emotional and Behavioral Disabilities

Mental Imagery

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Synonyms

Imagery; Mental visualization; Visual imagery

Definition

According to psychologists, mental imagery is a product of mental activity. When this product presents high levels of creativity and originality, it is usually referred to as "fantasy" or "imagination." On the other side, when this mental product concerns mainly the recall and/or production of events or objects that are very close to their actual perception, than we use properly the term of "mental imagery." We can use the term both if an actual sensorial stimulation is present or not.

Mental imagery can be hence intended as a phenomenon which is specifically determined by its relationship with sensorial characteristics that it can elicit, and that can easily be described referring to its structure and content. Adopting this perspective, mental imagery can be seen as a form for representing reality. Consequently, most psychological research has investigated it as a cognitive phenomenon that involves different levels of information processing, different sensorial channels, and that, at different stages of elaboration, has to consider the contribution provided both from the sensorial input and from previous knowledge.

Mental imagery often occurs in undirected thinking and also plays other specific roles in directed thinking, such as in memorizing, learning, problem solving, decision making, and motor control.

Theoretical Background

Historically, mental imagery has been one of the main inhabitants of human's mind. Human though was compared by philosophers to a sequence of images, which are similar to visual stimuli, without being real images.

Aristotle (384–322 BC) was one of the first to give to mental imagery a leader role – saying that thought would have been impossible without images, and that memory itself, even memory of abstract concepts, wouldn't exist without imagery. Other philosophers found quite suggestive the idea that thought and memory would depend on imagery – concluding that a concept was the same thing as its image. The only other possible alternative would have been hypothesizing nonvisual, hence verbal concepts. But words can't be assumed as main ingredient of thinking – since they are not innate. Using verbal sounds to communicate is natural for humans, but to be able to use them we have to learn their cultural shared meaning. The foundation of thinking should be something more basic. More, if every concept is stored in our mind as a word, how can we learn the very first word? Since mental images come from perception and do not require an arbitrary pairing with what they represent, they appear to be a more adequate candidate for the "original representation." Yet, also this theory has some weaknesses. During the eighteenth century, the Irish philosopher George Berkeley pointed out how it is hard to use imagery to store the concept of a class of objects (we tend to visualize a prototypic example and not the whole class).

Psychologists began to investigate the question at the beginning of last century, first of all Wilhelm Wundt. One of his main research topic was mental images – but he studied them using introspection – and hence his researches were affected by the weaknesses of this methodology.

John B. Watson in his contribution *Psychology as the Behaviorist Sees It* (1913) tried to trace a different path. According to his opinion, imagery is nothing more than a fiction, introduced by psychologists. Mental images are not mental representation but a form of subvocal thinking. Introspective data that seem to falsify Watson's theory could be easily disregarded since they can't be objectively tested. The author was convinced that the brain could be stimulated only by external stimuli: hence, nor thinking, imagery or other so-called "mental activity" would be generated by the brain. This general idea is, of course, the core point of Watson new school (*behaviorism*) – where each behavior is nothing more than a specific answer to a specific stimulus. Even thoughts are not seen as something originated by the mind but as a kind of behavior – a kind of discourse, to be more specific – activated by a stimulus.

After 1950s, behaviorism began to lose credit – and theoretical limits of this approach were highlighted. Even the concept of "stimulus" and "answer" were hard to be defined, and the mind quite hard to be denied or ignored. But the behaviorism succeeded in discrediting introspection as a valid research method. And mental events, such as imagery, were still seen as too "impalpable" to be scientifically explored.

Yet it was hard to reduce tout court the mind to the brain – and imagery was one of the aspects that were still unexplained. And it was not easy to believe that mental images do not exist while it is everyday practice to experiment them to remember or think about something.

So, while interest for imagery began to grow once again, questions around it were different. Psychologist didn't ask themselves only which role mental images have in thinking. They tried to find out the most appropriate way to define them and the most effective to discover their properties.

This new perspective derived mainly from a new point of view concerning the mind itself – aimed to distinguish two different questions: mental operations (such as memory, reasoning, perception, and so on) on one side, and conscious experience of this psychic activity on the other side.

Imagery could be studied scientifically focusing on the first side. Several researches pointed out how mental images couldn't be described only as an empirical subjective phenomenon, but also at a theoretical level since they are a form of representation of reality that influence cognitive and behavioral activity of individuals.

Mental images, from a theoretical point of view, were introduced as a way to counter the classical way to see knowledge inside a paradigm where the man is seen as a system to process information. This model does not expect any difference in representing different kind of data. Pictorial, linguistic, or olfactory inputs were completely changed to be translated in internal stimuli which had no structural relationship with depicted reality.

The first author to contest, with sever experiments, this proposition approach to knowledge was Roger Shepard (1971, 1978). At the beginning of the 1970s, he was able to demonstrate how humans can form mental images of more or less known objects, and to compare those images.

During the same years, Alan Paivio (1971, 1975) revealed how mental imagery can foster memory – presenting advantages with respect to a propositional representation of memories. He resumed ties between memory and mental images that were already known at ancient Greeks and Romans, demonstrating how words that had been stored with a dual code (verbal and visual) are memorized better that those memorized only verbally.

Yet, even if this renewed interest for imagery promoted many new researches, several incongruence emerged in this newly built relationship between theory and research on mental images. Indeed, some results were quite different from hypotheses derived from theoretical paradigms. Moreover, other interpretations were proposed to explain unique experimental effects. Furthermore, it was hard to frame in a univocal theoretical schema all the results gained using a wide range of experimental methods.

Hence, during the 1970s, many discussions concerning the actual nature of internal representation of mental images were born. Authors tried to define a common model and to clarify the role of imagery in high-level cognitive activities. The keynote question was if mental images have a functional role in thinking processes or if they are only epiphenomenal events associated with different processes that have none or limited pictorial attributes. Naturally, it was also important to define physical processes underlying imagery, and understand if and how those processes are isomorphic to external objects they represent. The debate that followed is commonly known as the dispute over the validity of the analogical model versus the propositional model of imagery.

The problem of image representation focuses primarily on specific or nonspecific nature of that representation. Is mental image a distinct form of internal representation, drawn differently than other forms of representation, or not?

The debate originated from an article by Pylyshyn (1973), which examines whether the concept of image can be used as a primary explanatory construct (i.e., a construct that does not require further reduction and that does not refer, to be explained, to other constructs) in the psychological theories of cognition.

According to the author, the representation corresponding to an image is more close to a verbal description of a painting than to the painting itself.

Visual representations, hence, are not pictorial, but constructions generated using the same procedures applied in the perception processes: they are built from the propositional structure, and then used as if they were real pictures.

In contrast, theorists who believe in the analogical model argue that mental images are "not analyzed representations," such as photographs and pictures. Highlighting that mental images of objects and events have behavioral effects similar to those that occur when objects and events are actually observed, they claim that imagery and perception are equivalent because they are governed by same rules and generated by the same structures and processes.

Pylyshyn's critique of this model is essentially directed against the use of the metaphor "picture similar to photography." This metaphor implies that what is received from memory, when a mental image is formed, must be taken into consideration, scanned, and interpreted perceptually in order to obtain significant information on the presence or absence of objects, properties, relationships, etc. Contrarily, Pylyshyn claims that mental images have already been interpreted and organized. As a proof of his position, he says that when we forget part of an image, what is missing is any object- or attribute-relevant material, not a marginal part.

Undoubtedly, on the one side Pylyshyn's criticism of the radical position of the metaphor "photographic image" is valid, but on the other hand, the theory of representation in terms of "propositional form" (which denies the specificity of the internal representation of the mental images) is not sufficiently supported and justified by compelling experimental data.

Anderson (1978) and Anderson and Bower (1973), while assigning a major role to the semantic and linguistic knowledge in different cognitive functions, and although they claim that a propositional encoding is needed to represent the meaning, they refuse to accept the arguments of Pylyshyn, believing that it is still an open question whether the "photographic metaphor" is erroneous.

Indeed, in their view, since we are unable to determine if internal representations are of a "pictorial" or "propositional" nature, lacking conclusive experimental evidence and physiological and neuropsychological data in this regard, both those who argue that all representations are propositional, and those who say that pictures representations are of a different nature, can commit errors of interpretation. In particular, Anderson bases this belief on a careful analysis on the one hand of the relationship between representations and processes triggered and used by these representations, and another side on the explanatory constructs that describe the nature of this relationship.

Important Scientific Research and Open Questions

It was Stephen Kosslyn (1980, 1981, 1983; Kosslyn and Shwartz 1977; Kosslyn et al. 1984) who gave the full dignity to mental images to represent a knowledge not attributable to any other modality and proposed a theory of imagery congruent with the paradigm of cognitive science.

According to him, mental images are not literally "images inside the head," but are mental representations that allow the experience to "see" something even in the absence of corresponding visual stimuli. This phenomenon results, at the same time, in a representation and in a conscious experience of representation itself. This functional union of parallel procedures (one to generate images and one to simultaneously make the subject aware of the unreality of the image, which is perceived "as if" it were before our eyes) is unique among the modes of representation of knowledge.

Kosslyn and Shwartz have also tried to simulate on a computer, using a standard algorithm, the generation of the image of an object, using lists of propositions containing information about the object. In that way, they also show the function of non-pictorial components of cognitive system. From this point of view, Kosslyn and his research team have attempted to develop a model with both analogical and propositional characteristics, which is considered of great importance for the understanding of specific cognitive processes of imagery.

Since the 1980s, Kosslyn devoted himself to translating his original model, so that it could also be represented in terms of brain mechanisms involved, trying at the same time to explain more directly the relationship between visual thinking and perceptual vision.

This "revisited" model was presented by the author in his book "Image and Brain" (1994) in which, starting from a detailed discussion of the perception of visual stimuli, he comes to outline a model of the perception of visual stimuli enhanced, if compared to that presented in previous works. The model has three major differences compared to the one previously developed by the author. First, the theoretical basis of this second version of the model is based clearly on the studies concerning visual perception rather than on those conducted on the subject of visual thinking. However (and this can be found as a second difference), Kosslyn suggests that the mechanisms responsible for creation of mental images constitute a fundamental and independent part of the process that underlies the recognition of a visual stimulus, not considering them merely as additional or optional features. As a third point, building the model on the extensive research he had conducted in neurological field, the author is able to propose specific locations for each of the neuroanatomical mechanisms assumed by him to explain his model.

Most of the research of experimental psychology, as it will be clear from the brief review above, has studied mental images, not as a result of a creative activity of the mind, but as a phenomenon that involves a set of cognitive processes concerning the development of information and that the various levels of analysis must take into account the contribution that comes both from the input from the sensory system and from knowledge acquired over time.

One criticism that could be raised is that research on mental imagery can't easily allow to conduct experiments which present, from an ecological point of view, natural situations. The conditions established in the experiments can only partially reflect the use of imagery that we do in real life, which, for example, is rarely the case of mental images produced on command for purposes known only to our interlocutor.

In our daily life, the mental images appear as the result of a cognitive strategy whose aim is to help us deal with situations and resolve issues in an articulate and, above all, easy way. When we are faced with a situation where we have to consider what we observe here and now, or something seen in the past, and is also necessary to anticipate and/or predict how things might look if seen from other points of view or other moments or if they were processed, moved, dismantled, etc. Then the mental images are formed as the most suitable and less expensive way to deal with the situation or solve that problem. In these cases, the mental images are triggered by an autonomous process that activates that specific type of elaboration, and not by someone who tells us what we have to visualize.

As we've seen above, in the perspective of cognitive science, imagery is a mental representation that gives rise to the experience of "seeing" something in the absence of appropriate optical stimuli. The ideal would then be to study directly this representation. Unfortunately, the phenomenon includes both a representation and the conscious experience, which, as we have seen, is likely to complicate things.

From the perspective of the person who has such experience, the image itself does not receive more attention than is customary to dedicate to the single colors or brushstrokes looking at a painting: in both cases, our attention is focused on the objects represented. Similarly, from the perspective of the subject, what is manipulated (noticed, explored in detail, enlarged, etc.) is the object represented, not the image itself. But we must not forget that, from the perspective of cognitive science, to be used is the representation, not the object represented. It is assumed that there is some connection between how mental representations are drawn and how the objects appear in the resulting images, and the exact "link" is precisely the theme of the theories we have examined. The problem is the fact that the mind, by definition, is a private matter. If we want to study mental events objectively, we need a way to make them publicly observable – but how?

The researcher of cognitive science can ask a person a question that involves the use of imagery to be answered, and see how long it takes to respond. Measuring the effects of mental activity (time spent, number of errors, etc), we can draw inferences about the activity in and of itself. If indeed mental images depict spatial extension, for example, we expect that it takes a proportionally longer time to explore larger distances visually displayed on an object mentally, which precisely matches the experimental data. Exemplary in this regard are the experiments conducted by Kosslyn (Kosslyn et al. 1978; Kosslyn 1980).

With regard to mental images, however, the problem seems to be more complex, because the information that we can derive from indirect actions of the people are reduced or nonexistent because, for example, we cannot find any nonverbal behavior corresponding to the experience of forming a mental image of one or more stimuli (Quinton 1973).

Researchers will therefore depend on the verbalization of these experiences by individuals, with all the limitations and risks that this procedure involves.

A successfully tested way to explore spontaneous visualization is the use of self-report questionnaires. One of the most used is the VVIQ Marks (1973), designed to measure individual differences in the vividness of their images. By crossing the results of self-report instruments, such as the one built by Marks, with the data that can be obtained by techniques related to neuropsychology, we can obtain particularly interesting data, which can, at least in part, allow to bypass the limitations of the self-report instruments. For example, laboratory studies have suggested that the subjectively reported variations in imagery vividness are associated with different neural states within the brain and also different cognitive competences such as the ability to accurately recall information presented in pictures.

Cross-References

- ► Learning and Thinking
- ► Learning Style(s)
- ► Mental Imagery and Learning
- ► Mental Representations
- ► Mental Rotation and Functional Learning
- ► Semiotics and Learning

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Mental Imagery and Learning

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Synonyms

Imagery and learning; Visual thinking and learning; Visualization techniques for learning

Definition

Mental images are often used in the processes of indirect thinking, such as in fantasies (Pope and Singer 1978; Singer and Antrobus 1972). It has been suggested that this mental activity performs a function of anticipation and planning, to help us not to forget the activities not yet completed and to maintain concentration when we are engaged in tedious tasks (Singer 1975). Moreover, the mental visualization plays specific roles in the processes of thought such as direct memory, problem solving, decision-making task, and motor control (Denis 1991).

All these specific features of visual thinking make it a particularly suitable candidate to support learning (both cognitive and motor), and have thus led to the construction of specific imagery training.

Theoretical Background

Western culture has generally underestimated the power of visual thinking.

Many theories, both philosophical and psychological, consider these forms of thought as preparatory or auxiliary to other forms considered more "noble," such as forms of logical, verbal, mathematical. Hence, visual thinking is seen either as a kind of thought that precedes the development of modes of reasoning that can work without images (a "springboard" for abstract thinking), or as a kind of "crutch" which occurs when abstract thinking is difficult (e.g., when we need to explain a concept to a person for whom it is difficult to follow logical proofs).

In other cultures, however, things are different. For example, in certain nomadic tribes, pastors realize the lack of any sheep in the flock, not counting the animals one by one, but through a simple "look" launched the flock. On the other hand, our school has accustomed us to play this function through a mathematical procedure, which is played here by a quicker visual process.

In some cultures, children's games also tend to develop visual abilities. For example, in parts of Africa, one of the favorite pastimes in childhood is to build piles of stones and then determine the exact number of stone just looking at them – the game is won by the child who is closest to the exact number of stones piled up. Visual–spatial strategies are also employed for solving complex problems. For instance, the inhabitants of Polynesian islands establish the orientation in navigation through spatial mental models, rather than – as we do in West culture – through a complex system of calculations.

Moreover, we can find in various oriental cultures educational practices which make use of mental visualization technique to help people overcome problems of an emotional or relational nature.

These suggestions are a clear indication that visual imagery can be highly effective for the solution of problems, and to cope with complex or new learning task. Also, the results of several experimental investigations prove that mental visualization can facilitate the solution of various kinds of problems or promote learning.

How and why does this happen?

First, visual imagery can be particularly productive since mental images can portray details and relationships that cannot be transferred from words, and can also bring new information compared to information represented with a linguistic formulation.

Using figural representations, we have also the chance to simulate a problematic situation and easily manipulate it. This happens because mental images are extremely flexible. They also allow changes to some elements of the problem on which we are working, even changes that would be impossible to implement in reality. This is particularly useful in learning situations because, sometimes, new problems, to be solved, must be set differently from the way in which they immediately present themselves. In these cases, mental images are useful because they allow to form an anticipatory representation of different solution strategies.

Imagery can be also used to "transcribe" elements of the problem in a visual–spatial format, maintaining a relationship of resemblance to the real situations. This we allow the learner to operate mentally on these elements in a more productive and realistic way than by using logical–verbal symbols (which imply a higher level of abstraction and a greater number of conceptual mediations).

Moreover, figural representations – for example, maps – allow to extrapolate from new situations the most important features, producing thereby a schematic overview, that highlight the essential structure of the problem or of the situation.

Imagery is also able to represent simultaneously different aspects of a situation. This feature is useful to help us to operate in ambiguity and uncertainty.

Important Scientific Research and Open Questions

The functions described briefly above, however, have been studied mainly in laboratory settings, and this could lead to advancing the doubt that the discoveries concerning the role of mental imagery in cognitive tasks cannot be generalized due to a lack of ecological validity (Yuille 1986). This lack is made heavier by the evidence that people, as trained to use imaginative approaches in cognitive processes, do not make use of mental imagery in everyday life (Katz 1987). We can therefore hypothesize that, generally speaking, the properties of positive mental visualization supported by the experimental results are not exploited.

Despite these doubts, however, numerous studies have also clearly shown that, in addition to having a specific role in everyday experience, mental visualization is also associated with specific cognitive tasks. It has been proven experimentally, for example, that visuospatial ability is related to mathematical and scientific skills, problem solving, ease of conceptualization, and reasoning (Kosslyn 1983).

Several investigators have shown a positive correlation between imaginative attitudes and execution of mathematical tasks. Because of this clear effect of imagery, it is clear the importance of developing specific training to improve the skills of individuals in terms of mental visualization. Usually, the results of these studies have been doubly effective, increasing the level of performance of spatial tasks, and all other activities that require special visual skills.

But, despite being recognized, the important role played by the cognitive field of mental visualization, we can find still relatively few research contributions focused on building training aimed to enhance visual imagery per se and which are not seen as mere means to develop secondary skills linked to imagery (usually motor skills).

A few examples of good experimental training to develop visual imagery in learning situation are reported below.

Parrott (1986) examined the effects of imagery training to promote the use of imaginative processes, comparing the results of the application of visual strategies with those of a program of training in the use of verbal strategies. The author examined the relationship between imaginative and space ability, their predictive ability in different contexts, as well as the manner in which the tendency to use preferably one of the cerebral hemispheres may influence the effect of imagery training. The data from this experiment did not allow to distinguish effects caused by hemispheric dominance, as a good execution of the various tasks was directly related to a cognitive style which did not involve a preference between the two hemispheres. However, several authors have demonstrated how the ability to make use of both hemispheres, or to alternate two cognitive styles, is better than a rigid reliance on a single cognitive style.

Techniques for teaching visual imagery in learning situation vary depending on the purpose of the research, which usually are centered on a specific sector (chemistry, mathematics . . .). In contrast, Louise Yates (1986) proposed to build a program to develop basic visual skills, and then linked the effectiveness of this training on the performance of university students in coping with tasks used to measure visuospatial ability. There was no evidence that the training has affected the spatial orientation. Although, by definition, the types of skills measured by the two tests used by the author were different and the correlation between their score had been found to be low, she expected the training could sort some kind of effect on the results of both tests. The reason for this lack of effectiveness is not clear: it could be due to the considerable difference in the averages of the results of the pretest between the experimental and control groups, or the belief on the part of the participants that the training would not be effective: a verbal strategy probably would have been equally useful and those that have used it in the pretest did not see the need to change it.

As is evident from the examples above, it is clearly and definitely – the link between visual thinking and learning is clear, but we still have to clarify how to build and test appropriate training for upgrading imaginative skills.

Cross-References

- ▶ Learning and Thinking
- ▶ Learning Style(s)
- ▶ Mental Imagery
- ▶ Mental Rotation and Functional Learning
- ▶ Mnemotechnics and Learning
- ▶ Visual Perception Learning

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Mental Leap

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Synonyms

Cognitive jump; Creative leap

Definition

Leap is defined as a sudden passage or transition (Merriam-Webster's Collegiate Online Dictionary. n.d.). According to Holyoak and Thagard (1995), a *mental leap* is required to suggest or understand analogical thinking, and it happens "like a spark that jumps across a gap, an idea from the source analog is carried over to the target" (p. 7). Thinking by analogy creates new connections between the two analogues, which initially seem unrelated, because the thinker recognizes the commonalities of the two situations. These abstract similarities create a transfer of knowledge. Analogy is guided by the three interrelated basic constraints of *similarity*, *structure*, and the *purpose* of the person who is using the analogy (p. 7). The following are four successive stages of the analogical thinking process (p. 15):

- *Selection*, in which a problem solver selects a source analog by retrieving information about it from his or her memory. It is guided by a similarity of elements and structural equivalence.
- *Mapping*, in which a problem solver maps the source to the target by active retrieval or by having someone point it out and thereby generates inferences (e.g., by finding similarities) between the source and the target. Mapping is controlled by structure, similarity, and the purpose of the analogy. The human mind generates analogical inferences using *attribute*, *relational*, and *system mapping* (mapping based on similar higher-order relations links them with a high degree of one-to-one mapping and structural consistency) (p. 31).
- *Evaluation*, in which a problem solver evaluates the inferences to determine whether they meet the purpose or not, based on the structural relations between source and target. Then the problem solver either adapts or abandons these inferences.
- *Learning*, in which a problem solver learns something more general (i.e., a schema which captures the patterns of relational structure) from the success or failure of the analogy.

Analogy requires concepts. Figuring out the similarity of shared features (e.g., recognizing sensory and semantic similarities) is necessary for the creation of concepts. Thus, understanding semantic connections between concepts is critical in analogical thinking because they serve as the building blocks for further understanding of higher-level analogies. In other words, analogy helps us to cumulatively form new and more abstract concepts and thus facilitates further complex analogies. This in turn supports the formation of more abstract concepts (p. 23). This is consistent with cumulative learning, which deals with the gradual development of knowledge and skills that improve over time.

Ward (1998) distinguishes between distant analogies, which are more likely to be associated with extraordinary forms of creativity, and near analogies, which are more likely to be associated with everyday, relatively small creative increments. Thus, he describes the distant analogies as creative *mental leaps* (e.g., Holyoak and Thagard 1995), while intra-domain conceptual extensions are creative *mental hops* (p. 222).

Cross-References

- ▶ Analogical Reasoning
- ▶ Intuition Pumps and Augmentation of Learning
- ▶ Mental Models

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Mental Load

► Mental Effort

Mental Logic

► Schema-Based Reasoning

Mental Model Convergence

► Learning-Dependent Progression of Mental Models

Mental Model of Dynamic Systems

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Synonyms

Mental models of dynamic systems, MMDS

Definition

Cognitive processes are any mental activity that acquires, stores, transforms, reduces, elaborates, or uses knowledge. Cognitive processes are also referred to as cognition.

Dynamic decision making is the process of assessing and choosing among alternatives at different times in the course of managing a dynamic system, that is, an environment that changes over time.

A *dynamic system* is one whose state changes with time. Dynamic systems are relevant to describe dynamic phenomena in many fields of research, for instance, in psychology, operations research, management, political sciences, sociology, and economics.

Model-based learning (MBL) refers to the activity of humans interacting with an external, formal model for the purpose of learning. The external model is used as a point of reference that structures and guides the learning process with the learner.

Model is a simplified representation of a real system. Models appear in this entry in the form of external and internal models. An *external model* is an explicit, mostly graphical representation of an internal (mental) model of an individual. It provides a means for communication and analysis. An *internal* (*mental*) *model* is a construct of cognitive psychology. Mental models are internal representations of conceptual and causal interrelations among elements that people use to understand phenomena.

Feedback is the transmission and return of information about the current output condition of a system. A *feedback process* is a process by which a system is controlled or changed by the output or response it produces.

Learning is considered a feedback process of the following kind: Our decisions alter the real world, we receive information feedback about the world and revise the decisions we make and subsequently the mental models that motivate those decisions. Learning can also be seen as a process of discovering the content and structure of a model or reality.

A *stock and flow diagram* (SFD) is a tool for graphically representing mental models of dynamic systems. Such a diagram is a means to represent the feedback structure of a system that consists conceptually of feedback loops.

System Dynamics is a computer modeling methodology that is used to represent and analyze complex nonlinear dynamic feedback systems for the purpose of generating insights and improving system performance. It has its intellectual origins in control theory, management science, and digital computing. It was created in 1957 by Jay W. Forrester of the Massachusetts Institute of Technology as a method for helping managers better understand and control corporate systems. Today, it is applied to topics in a wide variety of academic disciplines; see www.systemdynamics.org and the journal "*System Dynamics Review*."

Theoretical Background

Relevance of Mental Models of Dynamic Systems

It has been argued that today's world becomes ever more complex, interconnected, and dynamic.

Incremental and radical innovations are occurring at increasing rates in all pertinent areas of life with significant impacts. Because of this, human actions lead to counter-actions by others resulting in resistance against the original intention. In principle, the performance of activities is a process based on feedback, adaptation, and subsequent learning which is guided by the individual's mental models. A mental model reflects an individual's beliefs, values, and assumptions. It forms the reasons for actions. More formally, a mental model is an internal conceptual representation of causal interrelations among elements that people use to understand and manipulate reality.

Learning is essential for performance in reality. It is, in principle, a feedback process in which our decisions influence the real world, as a result of which we receive information feedback about the world and revise both the decisions we make and the mental models that motivate those decisions. However, experimental research demonstrates that people have a very poor understanding of even the simplest dynamic systems (Sterman 1994). In other words, their mental models of dynamic systems (MMDS) are not elaborated enough to capture the essential aspects of those dynamic systems. This is because learning in dynamic systems is constrained by several factors: The failure to register outcome feedback, ambiguous causal understanding, systematic misperception of feedbacks, nonlinearities, and time delays. To develop more useful and accurate MMDS, methods for enhancing learning about dynamic systems must overcome these impediments. Model-based learning with System Dynamics is one such method to address this (see Groesser, ▶ Model-based Learning with System Dynamics in this issue). The improvement of MMDS is of the highest relevance, since managerial and political decision making can be highly biased when the basic dynamics are not understood (e.g., Sterman 2008).

General Shortcomings of Mental Models

Mental models are theoretical concepts. They try to represent the cognition of an individual, that is, an individual mental model, or of a group of individuals, that is, a team mental model. Mental models are incomplete, overly simplistic, unstable, and highly flexible and thus inconsistent over time, ambiguous, and often open-loop models with narrow boundaries. These are some of the characteristics of mental models which have also been addressed by Herbert Simon with his principle of bounded rationality (Simon 1982).

Definition of Mental Models and the Mental Models of Dynamic Systems

Mental model research was first used by the psychologist K. J. W. Craik in his 1943 book, *The Nature of Explanation.* Since then, the term "mental model" has taken on a variety of meanings, all of which are still in usage. In psychology, for instance, mental models have been used as mental diagrams, mental representations, collections of beliefs, schemas, and knowledge networks. One current understanding of mental models in psychology is that a mental model consists of two or more assertions which are linked together. An assertion is a statement about a fact or a statement about the logical relationship between facts (Seel 2001).

Doyle and Ford (1998, 1999) have introduced the concept of a MMDS as an understanding of mental models that is more specific than previous mental model definitions. Groesser and Schaffernicht have provided an operational definition: "A mental model of a dynamic system is a relatively enduring and accessible, but limited, internal conceptual representation of an external dynamic system (historical, existing, or projected). The internal representation is analogous to the external system and contains, on a conceptual level, reinforcing and balancing feedback loops that consist of causally linked stocks, flows, and intermediary variables. The causal links are either linear or nonlinear, and can be delayed." (Groesser and Schaffernicht resubmitted, p. 22).

Relation Between Mental Models and MMDS

In the following, the relation between previous mental models and MMDS is provided. In principle, a MMDS is an instance of a mental model with special properties. The most important difference is that mental models in the previous notion are open-loop models, that is, models without any particular notion of feedback relations. A MMDS, on the other side, emphasizes the concept of closed-loop or feedback relations. This difference is essential because in an individual's open-loop mental model the dynamics arise from exogenous events, whereas in a closed-loop MMDS the dynamics emerge internally. A second difference occurs when there is more than one reason for an outcome to occur. In this case, the outcome is possibly explained by the existence of several mental models in parallel. From the perspective of MMDS, only one MMDS exists which encompasses all of the possible partial explanations for the outcome. The relative importance of the different partial explanations can vary, but the MMDS is a comprehensive representation of the individual's understanding of the situation.

Conceptual Structure of a MMDS

A conceptual structure of a MMDS, as shown in Fig. 1, shows the constituent elements in its framework. We can see a hierarchy in these elements, beginning with a feedback loop at the highest level. Feedback loops consist of the underlying elements, that is, variables and causal links. They are closed chains of causal relations which return information about the current output condition of a system to its input. A feedback loop has either a positive or a negative polarity. The former reinforces initial changes of a variable in the feedback loop; the latter counteracts changes in a variable within the feedback loop.

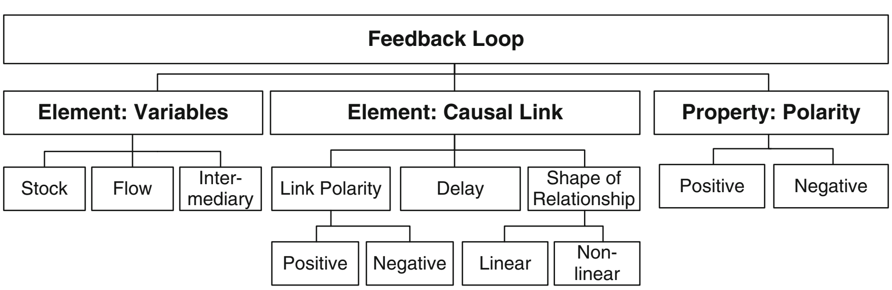
Variables constitute the second major group of conceptual elements. Variables can be conceived of as the knots in a network. Three types of variables are differentiated: Stocks, flows, and auxiliaries. Stocks describe the current condition of dynamic systems. They are accumulations of resources which can be measured directly (e.g., material, financial resources) or only indirectly (e.g., attitude, motivation). Flows, or flow rates, describe how stocks change over time, that is, flows are the means to change stocks. Auxiliary variables are neither stocks nor flows; they are intermediate variables which are used to formulate flow variables.

Causal links are the relationships between variables, that is, they are the connections between the knots in the network. They have three properties: Polarity, delay, and the shape of a relationship. The polarity, as in the case of a feedback loop, can be either positive or negative. For a positive polarity, an increase in the quantity of variable A leads to a subsequent increase in the quantity of variable B above the level it otherwise would have had (and vice versa for an initial decrease). Given an initial increase in the quantity of variable A, a negative polarity leads to a decrease in the quantity of variable B below the level it otherwise would have had (and vice versa for an initial decrease). A delay in a link indicates if the causal relationship is directly coupled in time (no delay) or if the effect lags the initiating cause by some interval. The shape of relationship between variables A and B can be either linear, that is, a change in variable A leads always to the same change in variable B, or nonlinear, that is, that a change in variable A leads to different changes in the variable B conditional on the current value of variable A. After defining the conceptual structure of a MMDS, the representation thereof is shown next.

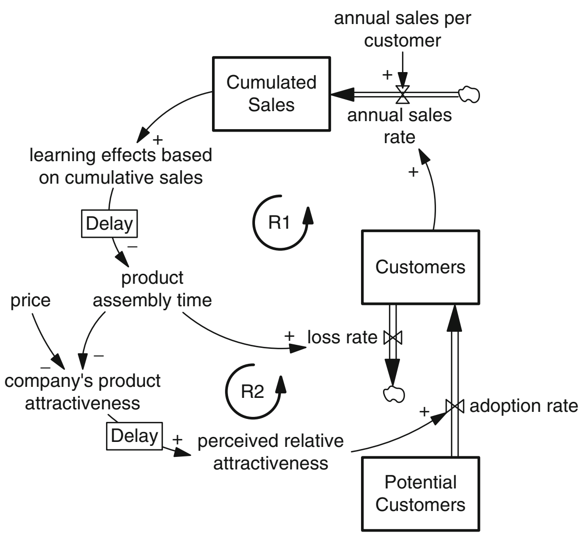
Representation of MMDS

Conceptually, MMDS consist of the structure as outlined in Fig. 1. Using this structure, the MMDS of an individual can be expressed. What is required is a representation method which is potent enough to account for all elements of the conceptual structure. A stock and flow diagram (SFD) is the method which best fulfills this purpose. Another frequently used method is a causal loop diagram.

In a SFD (Fig. 2), feedback loops are identified by R and B – R indicates reinforcing feedback loops,



Mental Model of Dynamic Systems. Fig. 1 Conceptual structure of mental models of dynamic systems (Groesser and Schaffernicht resubmitted)



Mental Model of Dynamic Systems. Fig. 2 Mental models of dynamic systems can be represented as system structure diagram

B would indicate balancing feedback loops. Stocks, which represent accumulations, are shown as rectangles (customers, potential customers); flow rates (adoption rate, loss rate, annual sales rate) cumulated sales are directly connected to the stocks. The remaining variables are auxiliary variables. Causal links between the variables are shown as arrows. The polarities of the links are assigned at the arrowhead (+ or −). Delays are represented by a box labeled with "Delay" (e.g., between a company's product attractiveness and its perceived relative attractiveness).

In the SFD in Fig. 2, the logic of an individual about the production and sales mechanisms of a company is shown. According to the thinking of this individual, customers who buy the products create sales for the company. The increasing number of products sold fosters accumulations in experience and learning about production and production management. This, in sequence, results in reduced assembly times, a fact which customers appreciate. Consequently, customers are more loyal to the company, thus leading to a lower loss rate. In addition, the higher availability of the products increases its attractiveness on the market. This is registered by potential customers with a perception delay. After this time lag, potential customers adopt the product, resulting in an increased customer stock. The owner of the MMDS perceives two reinforcing feedback loops (R1 and R2). It is obvious, however, that the MMDS is incomplete. For instance, the "perceived relative attractiveness" is a concept which is also influenced by other products available on the market. This is, however, currently not an element of the individual's MMDS. This MMDS example should clarify how a SFD is used to present the MMDS of individuals or teams. For more information on SFD, refer to Sterman (2000) and the literature cited therein.

Important Scientific Research and Open Questions

Research about MMDS is relatively new but nevertheless aspiring. It addresses among others the following questions: How are MMDS measured? How do MMDS change over time? Why is it that people who have relatively elaborated MMDS sometimes fail to apply them? Research about these topics is undertaken by experts specialized in Psychology and/or System Dynamics, for example, at the Worcester Polytechnic Institute, USA. (www.wpi.edu), at the University of St. Gallen, Switzerland (www.systemdynamics.ch), at the Universidad de Talca, Chile, and at the University of Bergen, Norway (www.uib.no/rg/dynamics). In the following, relevant research areas are outlined and briefly treated.

Conceptual Structure, Measurement, and Elicitation of MMDS

The comprehensive but parsimonious conceptual structure of a MMDS has been detailed in a previous section. The next step is to develop measurement scales and elicitation procedures to operationalize the conceptual structure. The difficulty, however, is that the mere act of trying to measure and understand MMDS might already alter the model itself. This fact leads to additional uncertainty in the measurement of mental models. Research about measurement and elicitation must use methods that are as naturalistic as possible, that is, that correspond to the settings, tasks, and question formats that people normally deal with when they think about dynamic systems (Doyle et al. 2008). Moreover, it becomes important to use elicitation methods that do not impose a particular structure, but allow the substantive structure to arise from the subjects' responses.

Evolution of MMDS

External representations of MMDS are only a snapshot of an individual's cognition at a specific point in time.

Changes of a MMDS can occur both over short and long periods. In principle, it is possible to compare the subsequent changes (Schaffernicht 2006). Schaffernicht and Groesser (2011) have developed a method of comparing MMDS which builds on and enhances previous measurement approaches (Langfield-Smith and Wirth 1992; Markóczy and Goldberg 1995).

Improving MMDS and the Results in Decision Making

Indications suggest that it is possible to enhance MMDS especially by the use of Model-based Learning with System Dynamics. By this means, it is possible to make mental models more complete, coherent, complex, dynamic, and feedback oriented. It is argued that the process of Model-based Learning with System Dynamics facilitates improving the learner's mental models by engaging in inquiry that is otherwise impractical or even impossible. Through the use of such tools, the cost in time and resources for learning iterations is reduced. Thus, the number of iterations can be increased, resulting in a potentially more detailed understanding of the problem at stake. In addition, Model-based Learning with System Dynamics can reveal the dynamic complexity of the systems; untangle inadequate and ambiguous outcome feedback; and can help to overcome misperceptions of feedback. By this process, MMDS can be elaborated. This has been shown by recent studies. For instance, Capelo and Dias (2009) conclude that learning interventions with System Dynamics computer simulations can lead to a higher degree of similarity among the mental modes of the decision makers. Sterman (2010) confirms that an education in System Dynamics is helpful in improving dynamic decision making. However, some well-documented cases exist in which improved MMDS failed to lead to better decisions. More research is required, therefore, to identify the contingencies under which both improving and utilizing improved MMDS can occur.

From Individual MMDS to Team MMDS

A further research avenue is the measurement and development of team mental models. Since research about MMDS is relatively new compared to research about common mental models, not many studies exist in this respect. It is advisable that research about team MMDS draw on existing studies of team mental models (e.g., Lim and Klein 2006; Mohammed et al. 2010).

In general, publications in recent years have shown an upward trend leading to a significant increase in the analysis of MMDS.

Cross-References

► Computer Simulation Model
► Dynamic Modeling and Analogies
► Mental Models
► Model-Based Learning with System Dynamics
► Feedback and Learning
► Simulation and Learning: The Role of Mental Models
► Simulation-Based Learning

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Mental Models

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Synonyms

Cognitive model representation; Internal model; Working model

Definition

Along with other types of cognitive structure, mental models are representations in the human mind of various aspects of an individual's lifetime experiences. Mental models are internal representations containing meaningful declarative and procedural knowledge that people use to understand specific phenomena. People can construct mental models in order to explain or to simulate problems, events, or future situations in mind, if no sufficient *schema* is available. A scientific analysis of mental models is very useful to optimize learning processes but depends on some preconditions. For example, an important precondition is an adequate measurable externalization of mental models. Another precondition is *consciousness* of knowledge which might be relevant for constructing a model.

Theoretical Background

Although mental models are often considered as a major theoretical construct of modern cognitive science closely related with the issue of knowledge representation (Markman 1998), the idea of mental models has a long tradition in the twentieth-century psychology and epistemology in which various roots can be distinguished. In accordance with neopragmatism and constructivism, mental models are widely defined as the mind's internal representations of real, hypothetical, or imaginary world phenomena. Usually, the idea of mental models is traced back to Kenneth Craik (1943), who argued that the mind constructs "small-scale models" of reality to anticipate events, to reason, and to underlie explanations. In other words, an individual who intends to give a rational explanation for something must develop practical methods in order to generate adequate explanations from knowledge of the world, using limited capacities for information processing in doing so. Thus, in order to create situation-specific plausibility, one individual constructs a *model* that integrates the relevant semantic knowledge and meets the requirements of the situation to be mastered. This model "works" when it is within the realm of the subject's knowledge as well as the explanatory need with regard to the concrete learning situation to be mastered cognitively. Like pictures in Wittgenstein's "picture" theory of the meaning of language, mental models have a structure that corresponds to the structure of what they represent. Since Craik's seminal work, cognitive scientists argue that the mind constructs mental models as a result of perception, imagination and knowledge, and the comprehension of discourse.

Parallel with emerging cognitive science, similar conceptions of internal or mental models have been adapted by scientists who were concerned with the pragmatic aspects of modeling (Stachowiak 1973) or the psychological investigation of experts operation with complex technical or physical systems (Veldhuyzen and Stassen 1977). Action regulation approaches consider mental models as the basis for mental simulations, anticipations, and regulation of actions. In addition, the conception of internal models also played a central role in information science in the 1950s and 1960s. Here, learning was considered as a complex procedure of constructing internal models of the environment (Steinbuch 1965) that were conceived as cognitive isomorphisms of structured domains of the environment.

Despite these early approaches, the concept of mental models became very influential in cognitive psychology and science, particularly in the 1980s. Actually, the emerging idea of mental models encompassed situated cognition as well as qualitative reasoning (Johnson-Laird 1983). In accordance with constructivism, the idea of mental models is based on two assumptions: (1) The person individually constructs the reality and (2) cognition and learning take place in the use of mental representations, in which individuals organize symbols of experience or thought in such a way that they effect a systematic representation of this experience or thought as means of understanding it or of explaining it to others (Seel 1991). Coherent *mental models* represent and communicate subjective experiences, ideas, thoughts, and feelings.

Johnson-Laird (1983) has described the representational function of mental models as follows:

- Mental models play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life. They enable individuals to make inferences and predictions, to understand phenomena, to decide what action to take and to control its execution, and, above all, to experience events by proxy. (p. 397)

Characteristic Features of Mental Models

Since the 1980s, theory construction and research on mental models became a prospering field in various areas, such as deductive reasoning, text and discourse processing, human-machine interaction, mathematical learning and symbolizing, science education (see, for example Ackermann and Tauber 1990). Clearly, there are "*[...] different concepts of mental models, but their same starting point is, that they will be constructed on the basis of recallable knowledge*" (Seel et al. 2000, p. 265) in order to comprehend the world. Mental models are characterized as individual, fragmentary, parsimonious, and in most cases unscientific. Mental models have also been seen as being involved in the regulation of action processes (see Hacker 2005). In sum, it can be stated that mental models are both implicit cognitive tools for and results of complex thinking.

People already start to create mental models in early childhood (Vosniadou and Brewer 1992). However, the construction process of mental models never really ends and goes one through the lifetime (see the entry on Mental models and life-long learning by Barker and van Schaik).

Schemas and Mental Models

Most cognitive psychologists agree on the point that cognitive schemas constitute the fundamental basis for the *construction of mental models.* In Piaget's epistemology, schemas serve, first of all, to assimilate information into pre-existing cognitive structures, whereas mental models can be seen as "tools" of accommodation (Seel 1991). In contrast to schemas, mental models are not permanent. While schemata are often absent, insufficient or inadequate for solving a given task or problem, mental models involve a restructuring of the cognitive structure which is useful for understanding a novel situation or an unknown problem. Mental models are cognitive constructions in problem situations which aim at subjective plausibility. As long as new information could be assimilated into the activated schema, a construction of mental models is not necessary.

In accordance with this view, Rumelhart et al. (1986) have suggested a cognitive architecture of information processing that contains two sets of units. One set – called an *interpretation network* – is concerned with the activation of schemas, the other one is concerned with constructing a "*model of the world.*" It takes as input some specification of the actions intending to carry out and produces an interpretation of what would happen if someone did that. Part of this specification could be a specification of what the new stimulus conditions would be like. Thus, the interpretation network, that is, a schema takes input from the world and produces relevant reactions whereas the second set, that is, the constructed *model of the world* explains and predicts how the input would change in response to these reactions. In the literature, it is common to talk about a *mental model* that would be expected to be operating in any case; insofar as it is generating expectations about the state of the world and thereby predicting internally the outcomes of possible actions. However, it is not necessary for world events to have happened. In case that they have, the cognitive system replaces the stimulus inputs from the world with inputs from the mental model.

This means that a "mental simulation runs" envisioning in the imagination the events that would take place in the world if a particular action was to be performed. Thus, mental models allow to perform actions entirely internally and to judge the consequences of actions, interpret them, and draw appropriate conclusions.

Numerous researchers defined the functions of mental models. A main function is, that mental models "run in the mind's eye." This is a central function for understanding, as it enables to find new solutions, analogies, and generalizations to explain reality or predict future events (see Al-Diban 2002). This function is very important for human decision making, because it constitutes an essential basis for comparing various alternatives in the mind.

A Comparison of Two Approaches to Explain Mental Models

The following discussion of two early approaches of the mental model construct will afford insight into this specific field of learning sciences. A dichotomous examination cannot take all theoretical postulated features into consideration. But the simplification should help to make correspondences and differences clear.

In 1983, the term mental model was coined mainly by Johnson-Laird. From this point on, mental models are generally distinguished from other forms of mental representation, such as images and *propositions* due to their different functions (Markman 1998). In contrast to propositions which have describing functions only, mental models are useful to explaining phenomena and solving problems. Mental models support long-term and well founded understanding. The different mental model approaches are largely in agreement on these two points. The differences start with the question of how these principles of understanding, explaining, and predicting emerge, and how the related processes work in detail. A comparison of representatives of the Cognitive Functionalism and the Epistemological Approach should make the various mental model building processes obvious (Table 1).

In Johnson-Laird's approach perception is essential; it is referred to as the "primary source of mental models – three dimensional cinematic models of the world" (1983, p. 406). Johnson-Laird assumes a broad correspondence between perceptions, encoding, and cognitive representations in the mind. He restated this point of view much later, pointing out that mental models reproduce "[. . .] what is true in one possibility, and so far as possible has an iconic structure"(Johnson-Laird 2006, p. 428). However, there is empirical evidence that visualization not always support model building processes (De Bock et al. 2003).

Another limitation of the Cognitive Functionalism becomes apparent when considering complex and not directly perceptible events like "photosynthesis," "air pollution," "radiation," or "inflation." The area of reference is restricted on directly perceptible or socially mediated phenomena. Johnson-Laird's approach combines epistemological assumptions of the coherence theory with pragmatism. The function of mental models is to intermediate between propositions and images. The main function of mental models is usefulness relative to the context in which it is used. As long as a mental model is useful there is no reason to develop new ones. Thus, the processes of conceptual change can be very restricted. This points to another weakness of the approach: How can questions about the changeability and development of the human thinking be explained?

The approach of Seel (1991) focuses on domain-specific knowledge and different ways to organize this knowledge in order to make sense of phenomena of the world and give them plausibility. Direct perception and analogue representations are not essential in this approach, but rather assimilative reconstruction processes of domain specific knowledge. Furthermore, this cognitive psychological approach assumes a subjective explanation value and internal consistency of mental models in addition to subjective plausibility. A qualitative distinction is made between so-called "everyday life models" and "expert models." Another assumption of this approach is that the "everyday life models" of novices and "expert models" have similarities due to their reference to reality as well as differences because of their different purposes. Novices construct models to ensure an adequate management of their own lives. For experts, on the other hand, the purpose of constructing a model is to observe, explain, and predict phenomena or events in general. Expert models are characterized by higher levels of abstraction, explanation value, and validity. This approach

Mental Models. Table 1 Comparison of two mental model approaches

	Johnson-Laird's (1983) cognitive functionalism	Seel's (1991) epistemological approach
Central assumptions: Mental models are seen as	1. Internal models of external and internal reality	1. Internal models of possible worlds
	2. Structures analog to corresponding facts	2. knowledge is consciousness about the world and a system of clauses ("sentences")
	3. Purpose determines content, form and level of representation	
Particular functions	1. Principle of economy	1. Reduction of complexity
	2. Mapping of identical structures	2. Reproduction of no-observable phenomenon
		3. Providing explanations
		4. Ability of mental simulations
Epistemology (theory of cognition)	1. Theory of truth (correspondence)	1. Theory of coherence
	2. Pragmatism	2. Theory of correspondence if applicable
Reference to reality	1. Perception based models	1. World knowledge
	2. Discourse based models, verifying in relation to the perception based model	2. Open, no special way
Consciousness	Obligatory	Obligatory
Language	Concepts as mental entities inclu-ding the assumption of hereditary semantic primitives and intentional correspondence between language expression and related reality sections	– Synthetic sentences: empirical founded, encyclopedic knowledge
		– Analytic sentences: rational founded, semantic knowledge
		– Symbolic sentences: without truth checking, subjective coherence, and consistence of knowledge basically for inferential thinking
Perception	*Central*: "It is therefore safe to assume that primary source of mental models – three dimensional cinematic models of the world – is perception." (1983, p. 406)	*Mediated*: "The cognitive system develops its 'worlds' exclusively on basis of the saved knowledge, without need of checking its propositions, beliefs, and assumptions directly in objective reality." (p. 144)
Mental modeling is conceived as	– Processes of *procedural seman-tic*: interpretations, evaluations, and revision of mental models:	– Operator schema with *assimilation resistance* supports accommodation
	Simply case: verification of discourse statements in relation to a perception based model	Mental models with help of "structural analogies"/"relation transfer" generated by processes of "abduction" (p. 138) or as "strategy of successive model construction and completion" (p.143)
	Difficult case: discourse based models without relation to perception (undetermined language discourses)	

posits two main functions of mental models. The first one consists of maintaining or producing explanatory coherence and subjective plausibility, and the second is explaining and predicting observable and no observable phenomena of reality. The epistemological assumptions are based on coherence and the theory of correspondence. The main function of mental models is to organize the area specific knowledge in order to lend subjective plausible to phenomena and give them meaning. Processes of conceptual changes are postulated based on analogical thinking and strategies of successive model construction and completion (Seel 1991).

Important Scientific Research and Open Questions

The majority of studies on mental models deals with topics in natural science education; only very few studies have been conducted on topics in the social sciences (see Caravita 2001). Furthermore, many empirical studies focus on quantifying methods, measurements, and criteria for describing externalizations of mental models (Hovardas and Korfiatis 2006). From an instructional point of view, there is great interest in assessing novice's mental models and comparing them with an expert's in order to identify the most appropriate ways to bridge the gap that usually exists between them. Meanwhile, there are as many assessment instruments as there are researchers working in the field of mental models (Ifenthaler et al. 2008).

The landscape of theoretical approaches to mental models becomes more and more differentiated. A highly promising new trend is that the interaction between cognitive and emotional factors will be taken more closely into consideration in order to clarify the importance of interaction between the quality of human thinking, self-confidence, and emotions (Merenluoto and Lehtinen 2004).

Cross-References

▶ Alignment of Learning, Teaching, and Assessment
▶ Belief Formation
▶ Emotional Mental Models
▶ Folk Psychology About Others' Learning
▶ Knowledge Representation
▶ Mental Models and Life-Long Learning
▶ Mental Models in Discourse Processing
▶ Mental Models in Improving Learning
▶ Mental Models of Environmental Problems
▶ Mental Representations
▶ Model-Based Learning
▶ Model-Based Reasoning
▶ Models and Modeling in Science Learning
▶ Models as Epistemic Tools in Engineering Sciences
▶ Simulation and Learning: The Role of Mental Models

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Mental Models and Lifelong Learning

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Synonyms

Cognitive structures; Human development; Learning; Learning community; Learning resources; Problem solving

Definition

The development of mental models is an important aspect of living and learning. These complex cognitive structures capture records of human experience and store them in the mind. They can subsequently be used for problem solving and goal-seeking activity. An individual's collection of mental models starts to develop at an early age and is continually modified during that person's lifetime. The set of mental models that are developed in early life may not be fully applicable to situations that arise in later life. During a person's life span, continual learning is therefore necessary in order to fine-tune these models – thereby ensuring their currency.

Theoretical Background

The theoretical background issues underlying the work described in this contribution falls within two distinct, but closely related and overlapping domains: mental models and lifelong learning processes. Each of these topics is briefly discussed separately in what follows.

Mental Models

There is a significant amount of contemporary literature available on the topic of mental models and the role that they play in relation to human cognition (Goswami 2008; Newman and Lamming 1995). An important aspect of this latter topic is trying to deduce how people store information and knowledge and, subsequently, how they use these resources in order to solve the problems that they encounter in their everyday lives.

There are many ways in which material (information and knowledge) is stored in the human mind. Collectively, the various artifacts that are available are generally referred to as cognitive structures (Newman and Lamming 1995). Some typical examples of such structures include: lists, schema, scripts, rules, decision trees, plans, procedures and mental models. Sometimes, the latter are referred to as "knowledge models." However, the latter term is also used to refer to external representations of mental models in the form of electronic or paper-based diagrams and concept maps (Novak 2010; 264–268).

As its name suggests, a list is simply an enumeration of a group of items having some characteristic in common – for example, the ingredients needed to make a cake, a shopping list, and the decimal integer numbers. In contrast, a mental model is a much richer structure that can embed different types of information and knowledge along with the relationships that exist between them. Mental models are important because they encode the experience gained from the learning (or unlearning) that takes place as a result of everyday living. For example, most people will usually have a mental model of the room or house in which they live. This would be a specific model about a particular place with which an individual has gained some level of familiarity as a result of experience with it. Such a model can be used to derive information that one would not normally wish to remember "verbatim." For example, by conducting a "cognitive walk" through one's mental model of a house, it would be possible to derive how many rooms it has, how many doors, how many windows, and so on. Naturally, the power of a mental model will depend upon the quality of the new information and knowledge that it can be used to derive. Most people would not, for example, remember the dimensions of each and every room in their house. They could not, therefore, calculate the floor space that they have available – with any degree of accuracy. However, if it was needed to know this, appropriate cognitive structures (that embed the necessary measurement and calculation procedures) could be invoked in order to derive this information.

As well as specific models about particular events, objects and processes, the human mind can develop more general models that apply to a wider variety of situations. These are often referred to as "meta-models" or "meta-knowledge." For example, most people who frequently travel by aeroplane will develop a generic model of an "airport situation"; they can use this model to predict what will happen while they pass through any specific airport and use the model to activate appropriate scripts as and when they are needed (arrival, customs, security, and so on) even if they have not ever visited that airport previously. As their familiarity with a new (to them) airport grows, so a specific mental model will develop – one which can accommodate their experience of that particular airport.

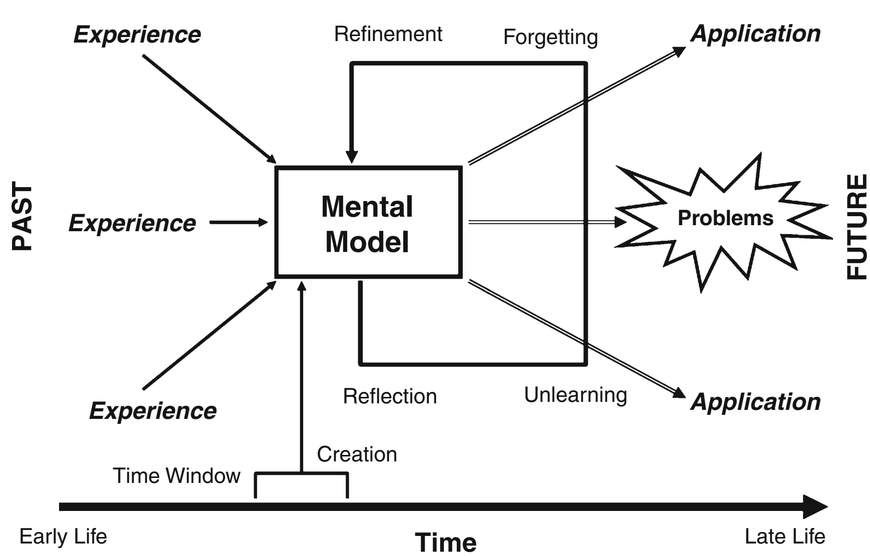
Mental models and their development within the human mind are very dependent upon the passage of time. This dependence is depicted schematically in Fig. 1. Naturally, an important aspect of mental models is their capability to adapt as a result of *reflection*, *unlearning* (or *restructuring*), and *exposure* to new (relevant) experiences. These mechanisms are important in relation to the process of refinement – whereby a model is "fine-tuned" in relation to the purposes that it has to fulfill (i.e., the applications to which it is put and the problems that it is used to solve).

As mentioned earlier, mental models provide a powerful means for storing personal information and knowledge. Of course, when storing materials, two broad possibilities exist: storing in the mind and storing on external (to the mind) media – such as paper, a mobile phone, or a computer. Naturally, through the process of exteriorization, material that is held in the mind can also be stored externally on an appropriate medium. Indeed, because of human cognitive limitations (Barker and van Schaik 2010), complex models may need to be partly stored on external media. We refer to mental models of this sort (where external support is used to augment the human mind) as "*distributed mental models*" as opposed to the "*internal mental models*" that are held solely in one's head.

Obviously, the nature of each of the mental models that a person has will change considerably during that person's lifetime. New ones will be created and old ones will be updated. As we have discussed elsewhere (Barker et al. 1998), it is therefore unlikely that the mental models people derive as a result of formal schooling (in the early years of their lives) will be completely sufficient to enable them to cope efficiently and effectively with the subsequent years that lie beyond their compulsory education. It is therefore necessary to consider what types of mental model are needed in order to overcome the shortfall; we discuss some of the possibilities later in the paper. Furthermore, with the growing importance of technology within people's lives, it becomes necessary to consider the roles of distributed mental models and the impact they are likely to have on the internal mental models that people create.

Lifelong Learning Processes

The development of mental models is likely to depend upon a range of different physical, psychological, and pedagogical factors. A more detailed discussion of some of the important psychological factors is presented in the next section.



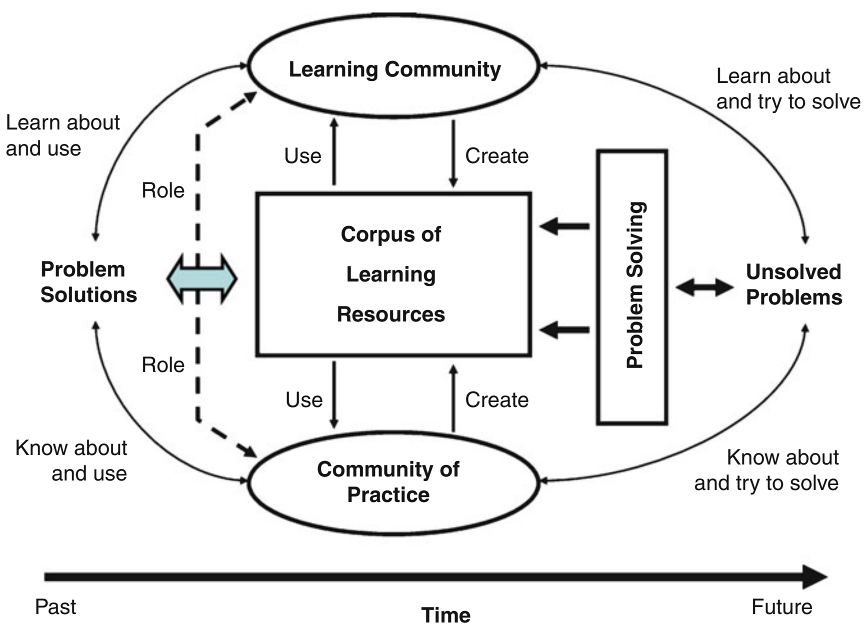
Mental Models and Lifelong Learning. Fig. 1 Conception and evolution of a mental model

Two crucial considerations in relation to learning are *perceptual processes* (and the availability of tools and technology to support them) and the *cognitive processes* that can be used to support the extraction and manipulation of data and information from what is perceived. Subsequently, the extracted material then needs to be integrated into existing cognitive structures and/or new ones created. Taken together, these processes are often referred to as *learning processes*.

In our view, there are two very broad types of learning: involuntary, innate or *autonomous learning* and directed or *intentional learning*. Autonomous learning is an ongoing lifelong process that involves assimilating an "awareness" of things and situations. This type of involuntary learning takes place throughout a person's lifetime. Intentional learning involves focussed exploration as a result of an individual's intent to find out more about something. This type of learning is strongly influenced by a person's interests, goals, and motivation.

Although a considerable amount of learning is an innate ongoing lifelong process, this usually has to be augmented by intentional learning processes. This is particularly true as people encounter new problems to solve and new tasks to be undertaken. For the majority of people, a considerable amount of focussed/intentional learning usually takes place during the first 20 years of their lifetime – in the form of "compulsory education" at school and college. In some cases, university education is a necessary requirement for professional acceptance. However, as we have noted above, the mental models that are developed in the "early years" of life will usually be insufficient to handle the "unknown" problems that are likely to occur in later life after formal education has ceased. Of course, we are not suggesting that intentional learning cannot or does not take place in subsequent stages of a person's life experience. On the contrary, we believe that new situations and new predicaments will often initiate "on demand" intentional learning as a result of the need to solve new problems that arise. Indeed, a person's changing circumstances is likely to generate a series of "need-to-learn" situations. In addition, a person's changing interests, hobbies, and activities is likely to create a "want-to-learn" dimension to an individual's motivation to learn. Bearing in mind what has just been said, one way to depict the need for and availability of lifelong learning opportunities is depicted schematically in Fig. 2.

This diagram depicts the relationship between a group of knowledgeable people in a particular domain (a community of practice or CoP) and people who wish to learn about that domain (a learning community). In this model, a problem-driven approach is



Mental Models and Lifelong Learning. Fig. 2 Learning resources and lifelong learning used as the underlying rationale for learning motivation. This is based upon our belief that "everything in life" is essentially a problem to be solved.

Fundamental to the success of the scheme depicted in Fig. 2 is the availability of a corpus of learning resources that would be needed to support the pedagogic processes that are an inherent aspect of lifelong learning. Some examples of the wide range of resource types available for the support of lifelong learning are listed in Table 1.

Because of the ease with which electronic resources can be distributed and shared, there is now an increasing use of e-learning (electronic learning) in both a conventional and a lifelong learning context. This can involve both individualized and collaborative learning scenarios. In addition, computer-based social networking is also becoming a powerful educational resource. These possibilities are discussed in detail by Mason and Rennie (2008), Holmes and Gardner (2006), Catherall (2005), and Salmon (2002). Of course, within a learning community, individual members are each likely to have different learning styles and preferences in relation to the mechanisms by which they learn and the locations wherein learning takes place. This means that, whenever it is possible, people would usually like to "mix and match" the ways in which they learn. Bearing this in mind, and considering the broad range of resource types listed in Table 1, the use of a blended approach to learning is also now growing in popularity (Bonk and Graham 2005; Barker 2008, 2009).

Mental Models and Lifelong Learning. Table 1
Resources to support lifelong learning

Conventional books and libraries
Electronic books and digital libraries
Communities of practice
Learning communities (both formal and informal)
Other people – social networks
Adult courses (conventional)
Online courses
Correspondence courses
Group learning
Electronic resources (TV, radio, video)
Virtual reality systems
Workplace situations

Important Scientific Research and Open Questions

When people finish their formal education, it is important to consider how they are likely to learn during the subsequent parts of their life. Naturally, this will be strongly influenced by their earlier life experiences. It is therefore our contention that within their compulsory study years "learning how to learn" in later life should be an important part of the compulsory curriculum (Novak and Gowin 1984; Barker et al. 1998). Of course, as was discussed in the previous section, adequate resources need to be made available to enable lifelong learners to study in order to gain the knowledge and skills that they need to acquire.

As people live longer, it becomes more important that they keep their mental models "up to date," with implications for problem solving and technology use. The reason is that mental models (and knowledge structures more generally) are required to perform particular tasks. Therefore, according to the mental-model hypothesis, the quality of people's mental models is correlated with their task performance.

Mental Models and Problem Solving

Although with increasing age comes a deterioration in cognitive abilities such as attention, memory, and information-processing speed, this does not necessarily imply a decline in problem-solving ability. For example, Hershey and Walsh (1993) found evidence for a lack of such a decline and offer two potential mechanisms. First, following from the mental-model hypothesis, complex problem solving is guided by the solver's mental model, indicating the variables that should be considered in solving a particular problem. Second, when dealing with complex problems, people's decision-making is often "satisficing" – that is, it is constrained by simplification and reduction, for example, in terms of the number of options that are considered. Therefore, as people age, they may develop richer mental models, and judiciously and selectively use these to guide their performance on problem-solving tasks. It follows then that by improving the quality of mental models, problem-solving performance can be enhanced or at least maintained throughout normal adult life, but this conjecture needs to be subjected to empirical testing.

Obviously, the increasing use of technology, in particular, interactive computer systems, in contemporary society offers further opportunities for users to develop their mental models and knowledge more generally.

It is important to realize that as people age, their motivation in relation to the types of problem they solve is likely to change considerably. For example, during a person's periods of employment, many of the problems addressed will probably be work-related. This implies that the types of problem addressed when a person retires from employment is likely to shift from those involving work-based issues to those related to newly developing personal interests. Although not discussed here, a study of the psychology of aging is an important area to study in relation to this issue (Belsky 1999).

Mental Models and Technology Use

In this section, the importance of mental models in technology usage is illustrated in the context of the growing importance of *information architecture* (Rosenfeld and Morville 2002). Information architecture involves a consideration of organizational structure, labeling systems, and the navigational structure available within an interactive computer system. According to Norman (1988), users will more effectively and efficiently employ interactive systems, if the underlying system model corresponds with its users' mental model of the system. This observation applies to interactive systems in general, but the importance of such a correspondence has become even greater since the 1990s with the proliferation of World Wide Web sites – and even greater still during the 2000s with the additional proliferation of personal publishing on the Web using weblogs and wikis. Computer users are therefore likely to be affected by the information architectures of Web-based systems (that are ever increasing in number) and by the information architectures of other software that they have on their computers.

The situation described above creates two problems. The first of these relates to the fact that the designers' and the users' conceptual structures (i.e., their [structural] mental models of the concepts that are the basis of the content of a Web site) may not match. Therefore, the information architecture, which represents a designer's mental model of a particular Web site, may make it difficult for a particular user (with a different mental model) to find and compare specific items of information. The second problem is that many "designers" of Web sites and, in particular, weblogs will probably not have been given any training in relation to information architecture. They are therefore more likely to produce difficult-to-use information architectures.

Unfortunately, these problems do not only apply to "published" web-based artifacts (e.g., sites or blogs) or interactive systems designed for use by others more generally, but also to systems designed for their own use. Consider the following powerful example. Anyone who has written a substantial computer program (without appropriate documentation and very clear structure, as often happens) and returned to examine or, even worse, edit the program after a few months will have experienced this problem: the program has become very difficult or impossible to comprehend! Arguably, one of the most common illustrations of the problem of using (or trying to use with difficulty) one's own mental model is people's "own electronic information architecture" (personal information architecture), that is, the organization of folders and files on their own computer: it can be very hard or impossible to find a particular item (e.g., an electronic document), depending on information structure (the way the information has been structured into folders) and labeling (the names given to folders and documents). The problem can be further compounded by the use of various types of storage device, such as the computer's fixed hard disk system, portable flash memory, compact disc, and portable hard drives, over which the information architecture is likely to be distributed or (partially rather than completely) replicated.

It is therefore important to consider the problem – for self and others – posed by externalized mental models in the form of information architectures and the proliferation of personal and externally published information architectures. Given this problem, the role of (self-) education in information architecture to produce more usable architectures becomes ever more important. In Nielsen's vision, presented in Rosenfeld and Morville (2002), (a simplified version) of information architecture should be taught at secondary and, perhaps even, primary schools. This will be needed to prepare people for a life in which they will create many personal and externally published information artifacts. While this vision of education has not been realized, people who have not undergone this training at school will need to develop the required knowledge and skills themselves.

A related research question is then: how should effective and efficient training materials (see Table 1) be designed for the population at large (not just for interested individuals) – at different levels of education that are appropriate to different segments of the population – to make them "information-architecture-literate"?

However, given the variability between people in terms of their life experience and level of cognitive function, education may not be sufficient to assist in producing information architectures that others and self can understand and use over time. Therefore, performance support for designers of information architecture would seem to be an essential complementary approach to the problem posed by externalized mental models in the form of information architectures. Psychological principles and guidelines have been proposed to identify and "repair" problems posed by poor information architecture. However, the fundamental problem remains that developers are most likely to produce information architectures for users that have similar mental models to themselves (Blackmon et al. 2005). (Given the apparent problem of finding information in one's own information architecture, even problems for self may not be identified at the time of designing this architecture!) However, automated methods hold the promise of supporting problem identification and "repair" for users with different background knowledge. For example, the *Cognitive Walkthrough for the Web* (see Web-Ref-01) is a (partially) automated technique that can be used to identify problems and "repairs" (Blackmon et al. 2005), in principle for user populations with different background knowledge (although separate analyses will have to be run for different populations). However, there are still several problems to be overcome in order to make effective and efficient automated support a reality. This is because existing techniques still require much "manual work" (e.g., users have to "submit" the characteristics of a web page, such as headings and links, to automated analysis) or they lack an (elaborated) underlying model of information architecture. Manual work can be replaced by capturing a Web site automatically and then analyzing it to produce a report of (potential) problems in the information architecture (see, e.g., Web-Ref-02). Still, modeling of the knowledge of various different user populations in one automated analysis and, arguably even more so, database modeling of the information architecture in terms of a psychological, validated model of information searching in web-based systems (e.g., CoLiDeS, Web-Ref-03) hold great promise for more effective analysis and "repair" of Web sites. A research question related to the need for performance support for designers of information architecture – (almost) all computer users – is then: how should effective and efficient electronic performance support systems be designed for the analysis and "repair" of both personal and externally published information architecture?

Cross-References

- ▶ Adult Learning
- ▶ Blended Learning
- ▶ Communities of Practice
- ▶ Human Cognition and Learning
- ▶ Human–Computer Interaction and Learning
- ▶ Knowledge Organization
- ▶ Lifelong and Worklife Learning
- ▶ Mental Models
- ▶ Problem Solving
- ▶ Schema(s)

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Mental Models in Discourse Comprehension

▶ Mental Models in Discourse Processing

Mental Models in Discourse Processing

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Synonyms

Mental models in discourse comprehension; Mental models in text processing; Situational models in discourse processing

Definition

Mental models have been invoked as an important explanatory principle for comprehension processes at a text/discourse level. Different depths of processing of a discourse can be detected on a continuum, starting from shallow levels – at which the listener constructs a mental representation of the discourse in a propositional format – up to deep levels of processing – at which the listener creates an articulated mental model of the contents of the discourse. A discourse mental model represents the state of affairs to which a discourse refers by integrating temporal, spatial, causal, motivational, and person- and object-related information stated explicitly in the discourse. Thus, a discourse mental model captures the discourse significance.

Theoretical Background

The earliest proposals advanced in the psychological literature to account for discourse/text comprehension stressed the relevance of propositional representations in accounting for comprehension, whereas more recent ones acknowledge the importance of more structured and elaborate representations such as mental models. The earliest proposals assumed that a text could be parsed into semantic units which are interconnected according to coherence relationships, and that comprehension was reached by adding together the semantic units, namely that discourse comprehension corresponded to the construction of a propositional representation.

Among the more recent proposals, van Dijk and Kintsch (1983) advanced the Construction-Integration model, according to which text comprehension involves two alternating phases: a construction phase and an integration phase. In the *construction* phase a text base is constructed in a propositional format from the linguistic input and from the listener's knowledge; the text base expresses the semantic content of the text. In the *integration* phase, this text base is integrated into a coherent whole. The initial text base may be potentially contradictory because it consists of a network of all the propositions formed directly from the linguistic input, all the relevant and irrelevant related concepts from the knowledge net, and all the inferences and elaborations made at the linguistic level. All these components associated with the text elements are included in the text base disregarding the discourse context, and many of them are inappropriate. The integration process excludes these unwanted elements; the representation that emerges from the integration phase is the *situation model*, which represents the situation described in the text.

Consistently, Johnson-Laird (1983) advanced the Mental Model Theory and assumed that, while reading a text or listening to a discourse, individuals construct both propositional representations and mental models: the former account for a representation of the linguistic form of the sentences, the latter for a representation of their content. According to the Mental Model Theory, in discourse comprehension individuals construct a model for each sentence, integrate such models also taking into account their prior knowledge, and consider what, if anything, follows. Thus, mental models also allow the reader/listener to draw inferences from the information explicitly stated in the text. These inferences depend upon the conceptual level and are distinguishable from those depending on the linguistic level, whose function is to fill the coherence gaps in the text. The inferences based on the mental model make explicit the information which is originally implicit in the text: they may regard, for instance, the causal antecedent, the causal consequent, or the character's mental states (i.e., beliefs and intentions) with respect to the actions described (Graesser et al. 1994).

The terms *mental model* and *situational model* can be considered equivalent, disregarding their different theoretical roots: they are an important explanatory principle for comprehension processes at a discourse level, since understanding a discourse is more than the mere understanding of a set of individual sentences and the construction of a coherent mental model or situational model is tantamount to the successful comprehension of a discourse or a text. Situational and mental models encode content information of the semantic and pragmatic sort, the individual's relevant prior knowledge, and any inferences that are drawn, but they do not generally encode surface information (the linguistic form of sentences) on which they are based. Several experimental results have shown that the listener/reader who constructs an articulated mental model of the discourse to which she/he has been exposed has a poor retention of the surface form of the text (see, e.g., Johnson-Laird and Stevenson 1970).

Important Scientific Research and Open Questions

Theories of discourse comprehension cannot disregard the role of co-speech gestures in constructing a discourse mental model; it is well known that co-speech gestures favor the comprehension of the discourse by the listener, and the literature suggests that speech and co-speech gestures function together forming a single, integrated system of communication. Kintsch (1998) recognized the importance of incorporating extralinguistic knowledge in the modeling of discourse processing; in the Construction-Integration model, images, perceptions, concepts, ideas, or emotions are translated into predicate-argument units because of practical considerations (Kintsch 1998 reprinted 2007). Within the theoretical framework provided by Johnson-Laird co-speech gestures convey information in a direct, non-discrete representational format that is particularly suitable to be inserted into a model representation, because mental models themselves are non-discrete analogical representations of a certain situation (Cutica and Bucciarelli 2008).

Cross-References

► Discourse
► Discourse Processes and Learning
► Mental Models

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Mental Models in Improving Learning

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Synonyms

Model-based instruction; Model-based learning; Model-centered learning

Definition

The mental model construct is used to describe the kind of mental representations individuals build when they reason about a certain matter; a mental model is an internal representation of a real or fictional state of affairs, and is usually built on-the-spot to deeply understand and reason about the state of affairs. Mental models that become permanent through cognitive or physical practice are schemas. Learners construct mental models in response to specific learning situations for which no schema is available or the available schema does not fit the situation. In other words, when confronted with new learning tasks, learners have to construct a mental model integrating their preexisting knowledge and the new information from the learning environment, along with proper inferences that can be drawn from these. This model has to be reconstructed several times to become a schema, i.e., to be learnt.

Theoretical Background

When learners face a learning situation for which no schema is available, they attempt to meet the requirements of the situation to be mastered by building a mental model which integrates the preexisting relevant semantic knowledge with the knowledge provided by the specific learning situation. Craik and Lockhart (1972) proposed different levels of processing during learning, from shallow levels (e.g., wording and syntax) to deep levels of processing (e.g., semantics) which produce longer lasting and stronger memory traces. The construction of a mental model is a high-cognitive-level activity which corresponds to in-depth processing of the situation, and therefore fosters deep learning.

The term mental model was introduced and used in a broad sense (see, e.g., the edited book of papers by Genter and Stevens 1983) until Johnson-Laird (1983, 2006) presented a single coherent view of what mental models are: special sorts of representations that have three characteristics distinguishing them from other mental representations (e.g., semantic networks, expressions in a language of thought or predicate calculus, connectionist webs of associations):

1. Each mental model represents a possibility – strictly speaking, a set of possibilities that have in common what the model represents. Thus, as compared to mental images, models are not specific representational formats, but more abstract representations. One specific learning task may therefore call for multiple models, which cause people difficulty.
2. Mental models are iconic, i.e., their structure corresponds to the structure of what they represent (the concept of iconicity goes back to Peirce who distinguished three properties of signs in general, in which he included thoughts. Signs can be indexical, symbolic, and iconic. Iconic signs represent entities in virtue of structural similarity to them). Hence, for example, people can "read off" relations from a model based on a spatial description, and they find it easier to reason from diagrams that facilitate this process.
3. Mental models are built according to the principle of truth, namely, mental models represent what is true, possible, according to the premises, but by default not what is false, impossible. Indeed, the model theory postulates that mental models are parsimonious: the principle of truth minimizes the load on working memory, and so it applies unless something exceptional occurs to overrule it. The principle applies at two levels. At the first level, mental models represent only what is possible. Consider, for example, how they represent the exclusive disjunction:

There is Jane at the party or else there is not Peter at the party.

Its mental models represent the two possibilities:

Jane

not-Peter

where each horizontal line denotes a model of a separate possibility. Hence, the first row in this diagram represents the possibility described in the first clause in the sentence, and the second row represents the possibility described in the second clause. At a lower level, however, a model represents a clause in the premises only when the clause is true in the possibility. For example, the first model in our example represents that there is Jane at the party, but it does not represent explicitly that in this possibility it is false that there is not Peter at the party, i.e., there is Peter at the party. The principle leads mental models to give rise to erroneous inferences. Previous studies have corroborated the existence of such erroneous inferences, and shown that they can be eliminated by using instructions designed to overcome the bias toward truth.

The mental model theory is the basis for theories of model-centered learning (see, e.g., Seel 2003). The construction and manipulation of mental models are processes through which learners make sense of a string of information (i.e., text, discourse, observation) within a consistent system of meanings and beliefs, from which they draw inferences. Hence, mental models respond to the learner's need to maintain the cognitive system free of contradictions or, say, cognitive conflicts. Thus, mental models favor learning because they allow the learner a deep comprehension of the information to be learnt, and the drawing of inferences that go beyond the information provided explicitly. For instance, in learning from a text, it is assumed that people construct a model for each sentence, integrate such models, and consider what, if anything, follows. When they behave rationally, people look for a model that falsifies the conclusion initially drawn in order to draw a new necessary conclusion, valid in all the integrated models of the premises. Consider, for example, the sentence "George came home before Claude." An analogical representation could be the following:

George t1 Claude t2

where tokens stand for the elements in the sentence, and are in the same relation as the elements in the sentence. Now consider the description "Claude came home before Vincent" and the respective model:

Claude t2 Vincent t3

The integration of the two representations through the overlapping of the common elements produces the following integrated mental model:

George t1 Claude t2 Vincent t3

from which it is possible to extract information that was not explicit in the sentences, and to infer that "George came home before Vincent," or "Vincent came home after George." As there are no alternative integrated models in which the conclusion is falsified, the conclusion itself is valid. When it is possible to construct alternative integrated models, the conclusion has to be supported by all of them.

The entire process of model construction and manipulation may involve a process of belief revision, necessary to construct a consistent system of meanings and beliefs. In general, when the model built is successful (i.e., when it is useful to the scope it has been built for), then it is reinforced; a reinforced model is a good candidate to become a stable model. On the contrary, when the model is not successful, or it has inconsistencies, then it is rejected, revised (i.e., some parts of it are modified), or elaborated (i.e., existing models are combined) in order to solve the noted deficiencies.

Further, mental models may improve learning because they aid in the visualization of either complex structures or systems. A series of studies in the literature prove the relevant role of visualization and model-based reasoning in different domains of sciences learning where explanations are largely based on entities and processes in the sub-micro world (see, e.g., chemistry, biology), or where distances and scales are too large to be grasped by direct perception (see e.g., geology, astronomy). Also, mental models aid in analogy construction from the structure of a known domain to the structure of an unknown one. In particular, learning can take place by means of analogical reasoning. Johnson-Laird (2006) illustrates how this process can take place through the case of Wilbur Wright, who drew several deep analogies between the bicycle and a heavier-than-air flying machine. His analogy depended on the manipulation of a three-dimensional model which allowed him to have an insight on how a plane can turn by twisting its wings in opposite directions without compromising the structural stability of the wings. Mental models also aid in mentally simulating processes or evolution of specific systems. This occurs when an individual interacts with the objects involved in a situation in order to manipulate them mentally in such a way that the cognitive operations simulate specific transformations of these objects that may occur in real-life situations; these simulation models operate as thought experiments which produce qualitative inferences with respect to the situation to be mastered (Seel 2006).

Sources relevant for building mental models are: the learner's ability to build models by induction, the learner's ability to observe the world, and other people's explanations. An important scientific question is, therefore, how can we foster the building of mental models through instructional strategies? Instructional strategies aimed at discovery learning, as compared to self-organized discovery learning, foster deep understanding rather that learning by trial-and-error. A number of different paradigms of model-centered learning have been developed: examples are instructional programs designed to help learners find their own answers (exploratory learning), or programs presenting well-defined concepts within well-designed conceptual models provided to learners (oriented learning).

Important Scientific Research and Open Questions

There are several open questions in the model-based learning domain. Among them is the issue of how to motivate the learner to change his/her model when it has sufficient explanatory power for everyday experiences. Indeed, individuals usually have a naïve understanding of a particular phenomenon, because they have a mental model based on everyday experiences. However, everyday models may need enriching or revising particularly when they differ a lot from the scientific mental models. The difference may cause difficulty for the learner and can be an obstacle to model revision. Thus, in science teaching, for example, it is important to help the learner to see differences and similarities between the two models, and to make scientific models more accessible.

A further relevant open question regards how to assess the learner's internal mental models. One way is to make the learner externalize his mental models, for instance, through concept maps, which can be monitored in different stages of the learning process, enabling the necessary interventions in order to foster learning. Externalization is an indirect assessment of the mental model, as the individual has to re-represent his own understanding of a phenomenon, in a different format. Think-aloud protocols can also be used to assess mental models, in particular, to assess the strategies used by the learner to deal with a learning task. To sum up, the quality of maps, diagrams, and think-aloud protocols may be taken as evidence for the general effectiveness of the instructional intervention (learning-dependent progression of mental models). A more direct way to assess the learner's mental models is to look at the inferences drawn on the material to be learnt. Indeed, proper inferences are supported by the construction of mental models, and the quality of such models can be evaluated through the type of inferences drawn by the learner.

Cross-References

► Cognitive Learning
► Mental Models
► Model-Based Learning
► Schema Development
► Learning and Understanding

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Mental Models in Text Processing

► Mental Models in Discourse Processing

Mental Models of Dynamic Systems, MMDS

► Mental Model of Dynamic Systems

Mental Models of Environmental Problems

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Synonyms

Implicit causal map of environmental problem situations; Internal representation of beliefs and ideas of environmental problems

Definition

Mental models of environmental problems are temporary cognitive structures formed in *working memory* and comprise information of natural and social systems in dynamically changing situations where controversial beliefs, values, and action models of a person himself and of other actors are simultaneously under consideration to guide the thoughts and decision-making actions in complex *dilemma situations*.

Theoretical Background

The clear, specific, and mutually agreed upon conceptual definition of the term *mental models of environmental problems* is missing. The definition is deduced from the *mental model* concept. The formation of dynamically changing representation of the environmental problem situation in *working memory* may be referred to as the *mental model* (Johnson-Laird 1983; Banks and Millward 2000). Johnson-Laird (1983) proposes mental models as the basic structures of cognition in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life. *Mental models of environmental problems* are consciously or unconsciously formed internal representations that integrate a person's knowledge, skills, competences, values, and beliefs about socioenvironmental systems, and their general social knowledge of actor roles, their values, beliefs, rules, and action models in the particular society, and support them at problem-solving and decision-making situations.

Following aspects characterize *mental models of environmental problems*:

- They are formed during *environmental decision making*
- They are temporary, unstable, and dynamically changing
- They get input internally from *long-term memory* (e.g., *social schemas, person schemas, role schemas, event schemas*) and externally from the perceived environmental dilemma situation components
- They are incomplete problem representations containing of limited and simplified information, which inhibits *rational decision making*
- They allow the coexistence and synthesis of several value frames and action models
- They presume arriving on consensus solutions rather than relying on one single solution overruling the others
- They may be dynamically shared during grounding processes in decision-making situations, enabling the formation of *shared mental models*

People are engaged in reasoned *decision making* about environmental matters on personal and community level on daily basis. The formation of their ► environmental awareness (Pata and Metsalu 2008) is tightly connected with the formation of mental models in these decision situations. On one hand, they abstract relevant aspects for understanding the situation from observations and relate these parts with each other. On the other hand, they selectively activate *schemata*, composed upon previously perceived representations of the similar problem situations, from long-term memory. The synthesis of externally and internally acquired information about environmental problems enables to build *mental models of environmental problems* dynamically.

Individuals judge impacts of the environment in different ways, depending on their experience, interests, and social context. Individuals' aesthetic, cultural, ecological, economic, educational, egocentric, ethical/moral, health, political, recreational, religious, scientific, and social value orientation influence their motives, strategies, and choice behavior (Hungerford et al. 1992). The confrontation of different attitudes and value systems, and the consequences of actions made on the basis of these attitudes and values, will cause *dilemma problems*. Environmental problems can be classified as dilemma problems. In his hierarchical classification of problems, Jonassen (2000) suggests that dilemmas represent the most ill-structured and unpredictable problem situations. Dilemmas are topically complex and interdisciplinary situated issues with antonymous positions and no solutions, which can be kept in balance by multiple reasoning and articulating preferences with justifications. *Environmental dilemmas* can happen both at individual-society level, as well as between several social groups of the community.

In environmental dilemma situations, the application of The Rational Choice Theory (Coleman 1990) is restricted. Individuals cannot evaluate the consequences of their choices without predicting how the other participants who are related to the problem will react. Rational decision making is also limited by time pressure in society – each decision made by any of the actors changes the decision-making setting and, thus, environmental awareness has to be generated dynamically by running mental models. Environmental dilemmas are characterized by complex polarities and interrelationship between groups of actors. The decision makers must have to deal with the probability-based decisions that different agents involved in the dilemma situation might be making, consider the role of other society members, and comprehend their environmental awareness in order to deal with the dilemmas. This presumes that the formation of an individual's mental model of environmental problems is simultaneously related with the formation of various *shared mental models* with different actor groups the person is in contact with (Banks and Millward 2000; Cannon-Bowers et al. 1993).

Dilemmas represent situations where groups of people do not have a shared mental model of the situation that in turn causes conflicts between their expectations and actions. Solving the environmental dilemmas presupposes establishing a cognitive consensus among these groups of people with different opinions (e.g., antropocentric, ecocentric) about the environment, increasing people's comprehension of the other group's value systems and action strategies, and as a result, building the *shared mental model* of the environmental dilemma issue.

Important Scientific Research and Open Questions

Environmental mental model mapping can support understanding of environmental problems and sustainability, support learning and decision making in dilemma situations. Studies that attempt to identify mental models of environmental problems aim to discover how the components of environmental problems are represented by different decision makers, and which changes take place dynamically in individual and shared mental models in case of intervention (e.g., Hukkinen 1999; Pata and Sarapuu 2003). Most of the challenges and limitations relate to the difficulties associated with isolating and studying mental models, in the capture and validation of the mental models. Mental models of environmental problems can be indirectly captured by: observing and explaining the problem-solving performance (interpreting the recorded actions); or reflecting the problem-solving performance (various textual, audible, or visual representations are composed dynamically while solving problems, with certain time intervals, or after problem solving).

Most studies elicit mental model information using certain qualitative analysis techniques and analytical categorization schemes. For example, the cause-and-effect networks drawn from the individual narratives was used in combination with Bayesian network analysis to reveal mental models of environmental problems (Hukkinen 1999); the dynamical discussion data was used to demonstrate the changes in the structure of individual and shared mental models of environmental problems (Pata and Sarapuu 2003).

Besides the theory of considering mental models as cognitive structures, the other eco-cognitive explanations of the *distributed cognition* exist (Magnani 2009). It is assumed that humans do not hold a complete internal representation of the environment as is proposed in mental models of environmental problems; instead they use the environment itself as a representation by manipulating and even creating it so as to find room for new cognitive chances not immediately available.

Cross-References

- ► Model-based Reasoning
- ► Mental Models
- ► Schema(s)
- ► Schemas and Decision Making
- ► Shared Cognition

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Mental Objects

► Representations, Presentations, and Conceptual Schemas

Mental Orthographic Images

► Mental Graphemic Representations

Mental Orthographic Representations

► Mental Graphemic Representations

Mental Practice

► Imagination Effect

Mental Presentations

► Representations, Presentations, and Conceptual Schemas

Mental Processes of Learning

► Mental Activities of Learning

Mental Rehearsal

► Imagination Effect

Mental Representation

► Mental Rotation and Functional Learning

Mental Representations

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Synonyms

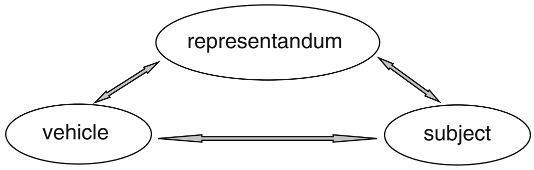
Imagination; Internal representation; Mental model; Schema; Script

Definition

The notion of a "mental representation" is a theoretical construct to explain ongoing information processing in the human brain. A mental representation is to be distinguished from external representations in the world which are used as a stand-in for something else, such as an architectural which stands-in for a house. There are four necessary components of representation:

1. The vehicle (the medium, the representation itself)
2. The representandum with semantic properties (the content, the referred-to object)

3. The subject (having/using the representation)
4. The triadic relation between those components



If a subject is employing a mental representation, the representandum is realized by the vehicle and provides information for the subject. As we will see in more detail below, it is important to distinguish between mental representations, with cognitive content, and any structure-preserving presentation, such as pictures.

Theoretical Background

The Vehicle

Given the notion of "mental representation" is a theoretical construct; we do not need to specify, at this point in time, the precise constitution of the vehicle. Further development of neuroscience will specify the corresponding states and processes. The interesting question is not how and what is realizing the vehicle but what functional features go along with it and what kind of structural features can be assumed. The structural properties of vehicles will be treated below. Functionally, a vehicle of mental representation can be characterized as an inner state that is realized in the brain which plays a role in ongoing computational processing.

The Representandum

The content of a mental representation is called the representandum, which can be an object. This object can be an event, an object in the world, a fact, or another mental state like a memory. The representandum has semantic properties, for example, it can be true, accurate, appropriate, adequate, or consistent. A necessary condition for a representandum is the existence of an interpreter, in the case of mental representations the subject employing the representation.

The Triadic Relation

A representation is not just an accidental copy of the referred-to object. What is required is not just the vehicle and the representandum, and the subject but also a triadic relation between them. The relation between the vehicle and the representandum must be interpreted by a person or a system. Being a representation is not a property of something itself; a vehicle can only be a representation if it is used as a representation.

There is no universal theory of the triadic relation: theories differ depending on the type of representations they are characterizing. This is due to the fact that different types of representation have varying relations between their components. This can be illustrated by looking at the explication of sensory (non-conceptual) representations in opposite to conceptual ones:

- For the general case of *sensory, non-conceptual representations* a *causal theory* seems to be adequate to capture the triadic relation between the vehicle and representandum. One can describe this causal link in the following way: A stimulus evokes a reaction/response in the sensory systems (organs) and together with some sort of information processing a representation of this stimulus evolves. The representation of a visual stimulus is caused by the represented stimulus and the involved information processing. Consequently we can claim that the representandum has semantic properties such as being appropriate or adequate. So we can talk about a hallucination as being inappropriate because it is a representation of a non-existing object and therefore without a direct causal link to the representandum. A possible objection is the fact that hallucinations also presuppose a memory of sensory sensations. Taking this into account, you might talk about a relation to existing inner objects instead of a relation to outer stimuli. Another way out could be to name a hallucination a misrepresentation.
- *Conceptual representations* (comparable to non-pictorial, language-like representations) preserve some or all of the relations between the representandum(s). Some essential relations of the referred-to object are chosen and represented. A *theory of structural similarity* provides an account of one part of the triadic relation, namely, the relation between the vehicle and representandum. Taking into account that the content of a representation (the representandum) can only have a meaning if it

is playing a functional role for an interpreter, a *functional theory* can describe the relation of the subject to the representandum (Cp. Vosgerau 2008). The notion of conceptual representations has been used in the automata theory of human behavior. This theory combines the symbol-system hypothesis, which claims reasoning as symbol manipulation with the Church-Turing thesis which claims that any symbol manipulation can be carried out on a Turing machine. The automaton theory describes the behavior of an automaton by a function, defining the mapping of a state of the automaton plus the input and the consequent internal state plus the output. This can be illustrated by the description of a soda machine reacting differently depending on whether money has been inserted (internal state 1) or not (internal state 2). Whether or not money has been inserted is represented through the two distinct inner states of the machine, and those states determine the further behavior of the machine, namely, whether or not a drink is dispensed. Analogously we can refer in the human case to inputs (sensory sensations, internal states, or mental representations), outputs (behavior), and following changes in internal states (beliefs, desire, etc.). By positing an inner state (a mental representation) we can explain why humans are able to react in a flexible way to one and the same input. The idea is that internal states by representing information that goes beyond that contained in the input can serve to enable more flexible information processing.

Important Scientific Research and Open Questions

The Subject

There are open research questions regarding all three components of representation, namely, the subject, the vehicle, and the representandum. To start with we will focus on the subject that employs a representation. Not all information a subject is using is directly accessible to the subject. At least some mental states can be *unconscious*. Data from neuroscience show that persons can gain and use information without being aware of it. Looking at their behavior one can refer that they must have had access to information. The most radical example of an unconscious non-conceptual representation is the phenomena of blind sight (Cp. Weiskrantz et al. 1974). The subjects are convinced that they do not see but their behavior is explicable only if one claims that visual information is used by the subjects. This representation is still a representation even though the subject only unconsciously uses it. The fact that such representations are required to provide an adequate functional explanation of behavior demonstrates that they exist even though the conscious subject is not aware of them. One can question whether such unconscious representation should count as mental. For example, the ability to maintain a constant temperature can be explained by a representational theory but those representations seem to be body not mental representations. However, it seems that it is only if information is used in intentional actions, as it is in the case of blind sight that it seems to be justified to describe them as unconscious *mental* representations.

But it is not clear whether all mental representations can be unconscious. Most striking are the debates about "unconscious pain." Assuming first that conscious pain can be seen as involving a mental representation, the functional role of this representation is to inform the subjects about a damage of her body. Together with the phenomenal content this makes it possible for the subject to react in a way to avoid more severe damages. An "unconscious pain" then would give such information to the system and the system evokes a behavior trying to avoid the increase of that damage. But it is good question whether this still should be called pain because it seems intuitively clear that pain is painful and a non-painful pain would be a contradiction in terms. Nevertheless, it seems uncontroversial that human beings are able to represent damages of their body without consciously feeling them, otherwise it would be difficult to explain, for example, relieving postures in connection with orthopedic problems. Such unfelt pains would rather count as bodily representations.

Formats of the Vehicle

Taking a closer look at mental vehicles and at findings out of neurosciences it seems possible to map specific brain activations to specific thoughts or intentions (Cp. Haynes and Rees 2006). It is important to appreciate the diverse terminology used to refer to the different formats of mental representations. Notions like schema, scripts, and mental models have in common that they describe how representations can be organized. Focusing on the so-called mental models (Cp. Johnson-Laird 1983), they are understood as a conceptual framework of representations of knowledge. This knowledge can be related to the person itself (self-model), to parts of the world (world-model), or to abstract correlations. Many other notions have been introduced to describe structuring features of representations. Just to name some: semantic maps, concept maps, or an individual's knowledge structure described as a data association array, retinal arrays, primal sketches and 21/2-D sketches (Marr 1982), frames (Minsky 1974), and interpreted symbol-filled arrays (Tye 1991). Each of these focuses on a certain type of referred-to objects (representanda) and claim that the vehicle has corresponding structural properties. Taking for example the distinction between pictorial and non-pictorial representation (Kosslyn 1980), non-pictorial representations are seen as discrete or digital where as pictorial ones are described as continuous and analog. Of course, you can also think of a hybrid form having pictorial and discrete elements. Philosophical positions like the computational theory of the mind (Fodor 1975) or connectionism also claim structural properties of mental states.

Special Cases of Mental Representation

Special cases of mental representation open up questions concerning the above described conditions of representation. When the representandum is a memory of a former mental states one might question whether there really is structural similarity or even a causal link to the former mental representation. Empirical studies about memory have shown that so-called false memory (Loftus 1980) is more often observed than as one might intuitively believe. How do we call the mental representations of false memory? Would it be adequate to call them misrepresentations ignoring the fact that memory has a constructive part?

We have seen that mental representations can be explained either by a causal theory or by a theory of structural similarities and that in both cases the representandum has semantic properties. If, in case of a causal explanation, the stimuli are only represented in a deficit manner or if the stimulus is lacking at all we talk of misrepresentations. But how should we describe a mental representation where the referred-to object seems to be absolutely new? If the representandum has neither a causal relation to a stimulus nor a structural similarity to the referred-to object one had consequently to admit that this kind of representation does not fulfill the condition of having semantic properties. One possible way out would be to give up semantic properties as a necessary condition of representation or one could claim that human beings maybe are just not able to have mental representations with an absolutely new content rather claiming that the new is more or less a question of a unexpected recombination of already known elements.

Cross-References

► Connectionism
► Human Cognitive Architecture
► Knowledge Representation
► Mental Imagery
► Mental Models
► Philosophy of Learning
► Psychosemiotic Perspective on Learning
► Schema(s)
► Semiotics and Learning

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Mental Resources

► Multiple Resource Theory

Mental Rotation and Functional Learning

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Synonyms

Mental representation; Motor simulation; Spatial ability

Definition

Mental rotation is a cognitive operation during which a mental image is formed and rotated into a different orientation in space. Such process usually requires cognitive manipulation and spatial transformation of a two-dimensional or three-dimensional object. Interestingly, it may also involve the rotation of body parts or shapes with embodiment effects. Two mental rotation paradigms are usually distinguished: the perspective tasks require to determine how an object would appear from a different viewpoint, while in comparison tasks, changes are not related to the individual, but to the object itself. The aim is, therefore, to determine whether pairs of visual stimuli, presented from two different angles, are identical or mirror images. Response time and accuracy are the most frequent measures of performance.

Theoretical Background

While mental rotation paradigms can be traced back to the late 1960s, the most famous study dealing with this issue was published by Shepard and Metzler in 1971. By presenting the participants with pairs of three-dimensional asymmetrical assemblages of cubes, they provided evidence that response time was proportional to the increase of the angular disparity between pairs of items. Mental rotation time would therefore be similar to the time course of a physical rotation with constant angular velocity. Later, mental rotation time of body parts (or mental rotation of shapes with added body characteristics) to a given orientation was shown to be dependent on how awkward the initial orientation was. These data provide evidence that mental rotation of body segments depends on the biomechanical constraints of the actual movement (Parsons 1987).

There is now compelling evidence that men and women differ in performance on mental rotation tasks, but the causes of these differences are not well understood. Overall, several promising hypotheses referred to sociocultural or biological differences. The way in which problems are solved, the amount of time needed to resolve the mental rotation task, and the nature and complexity of the items to be rotated, are influenced both by gender and previous personal experience, and most certainly by the complex interaction among these factors. Unfortunately, no agreement has been reached in regard to each of these issues. However, both men and women have been found to significantly improve their mental rotation performance following either mental rotation practice.

Practically, mental rotation is involved in spatial reasoning and problem-solving such as spatial orientation and mental navigation using map displays. More generally, real-life situations rely on the ability to use mental rotation to turn over and manipulate objects mentally. In the last decade, there has been an increasing amount of research investigating the neural mechanisms mediating mental rotation, as well as the influence of mental rotation ability on learning.

Important Scientific Research and Open Questions

Neuroimaging studies provide a valuable means to determine the neural substrate of mental rotation. Zacks (2008) concluded that many brain regions including the superior parietal, the frontal and the infero-temporal cortices, were consistently involved during mental rotation, with many bilateral foci of activation. Overall, these findings support the view that mental rotation depends on analog representations, as well as ► motor simulation in some cases. The modulation of activity in the pre-central cortex would even reflect the extent to which participants adopt a motor simulation strategy to solve a mental rotation task (Zacks 2008). Practically, another important question is whether the mental transformations associated with object-relative and egocentric reference frames are subserved by different neural mechanisms. Motor areas are active during egocentric rotations, but not during object rotations, hence suggesting that only mental rotation tasks involving body parts would elicit motor strategies. These results demonstrate that different types of mental rotation involve distinct neural networks, although Wraga et al. (2003) went further and showed that motor activations could also transfer implicitly across these mental rotation tasks in some occasions.

Another field of research is the role of ► spatial ability, including mental rotation, in functional learning. In the medical field the learning of both functional anatomy and surgery procedures has already been considered (e.g., Garg et al. 2001). Overall, students with high spatial and mental rotation abilities are favored in the acquisition and retention of functional anatomy knowledge, and, moreover, they obtain better results in surgical procedures than those with lower abilities. These results collectively suggest a transfer of the ability to perform object rotations to mental rotation tasks involving egocentric transformations, and give the opportunity to use spatial ability and mental rotation tests as part of a battery to assess students' potential for success in anatomy. The effects of mental rotation training on anatomy learning and the internal process of such a transfer have also been studied recently (Hoyek et al. 2009). Results confirmed that high mental rotation ability may facilitate the learning and retention of anatomical knowledge, and further revealed the existence of a transfer of mental rotation abilities from a task requiring rotation of two- or three-dimensional items to a task requiring transforming body segment and complex anatomical structures. These results emphasize the previous findings related to health science education and the argument that spatial ability and mental rotation training could help students in various scientific and medical disciplines.

Interestingly, transfer between mental rotation abilities and complex motor skills including body rotations and changes in direction could be effective as well. Theoretically, if mental rotation and motor performance share similar mental processes, enhancing mental rotation ability or its subprocesses might thus be transferred to the physical execution of a given action, and therefore contribute to achieve peak performance. This line of research is far less extended, and there are currently too little existing data allowing determining the nature of these common materials. Hence, future investigations should attempt to define in greater details the relationships between mental rotation training and motor performance.

Cross-References

- ► Abilities to Learn: Cognitive Abilities
- ► Cognitive Learning
- ► Functional Learning
- ► Human Cognition and Learning
- ► Imagery and Learning
- ► Mental Imagery
- ► Mental Imagery and Learning
- ► Mental Representation
- ► Science, Art and Learning Experiences
- ► Spatial Learning

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M

Mental Set

Old, less efficient patterns of problem solving persist even though more efficient solution alternatives exist.

Mental Simulation

► Imagination Effect

► Simulation and Learning: The Role of Mental Models

Mental State Attribution

► Theory of Mind in Animals

Mental Toughness

► Resilience and Learning

Mental Training

► Learning by Doing Versus Learning by Thinking

Mental Visualization

► Mental Imagery

Mental Workload

► AIME (Amount of Invested Mental Effort)

Mentalist Theory of Language Learning

A theory in the tradition of Noam Chomsky which emphasizes the learner's innate mental capacities for language acquisition.

Merging Knowledge Structures

► Knowledge Integration

Message

► Communication Theory

Message Transmitters

Message transmitters include both print and nonprint media that contain and convey information, ideas, values, and ideologies from a source, or sender, to an audience, or receiver.

Metacognition

Metacognition is an individual's awareness of his or her own cognitive processes. With respect to learning, this can be interpreted as an individual's awareness of what they have and have not learned. Metacognition is essential for learners to in order to self-regulate and guide learning.

Cross-References

► Introspective Learning and Reasoning

► Metacognition and Hypermedia Learning: How Do They Relate?

Metacognition and Hypermedia Learning: How Do They Relate?

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Synonyms

Metacognition; Metacognitive monitoring and control; Multi-representational learning environments; Scaffolding hypermedia; Self-regulated learning

Definition

Metacognition, often refered to as "thinking about thinking," is defined as "one's knowledge concerning one's own cognitive processes and products or anything related to them, e.g., the learning-relevant properties of information or data. [. . .] Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in the service of some concrete goal or objective" (Flavell 1976, p. 232).

Contemporary definitions of metacognition characterize it as an individual's cognition about his or her own cognitions, knowledge of and control over one's own cognition, cognition that reflects on, monitors or regulates first-order cognition or knowing about knowing (for an author overview, see Opfermann 2008).

Metacognition and self-regulatory processes are especially important in open-ended learning, e.g., in nonlinear, multi-representational hypermedia learning environments. Hypermedia environments are also characterized by a high level of interactivity and network-like information structures (Scheiter and Gerjets 2007) which require learners to use metacognitive skills in order to make decisions that are enduringly required due to the high level of learner control. This chapter focuses on the relationship between metacognition and hypermedia learning and emphasizes the importance of metacognitive skills and self-regulatory processes for learners to benefit from these environments.

Theoretical Background

The importance and popularity of interactive learning environments has grown rapidly in the last few decades. Specifically with regard to hypermedia environments, their network-like structure allows learners to retrieve information flexibly, thus offering a high amount of learner control with regard to representational and navigational choices. A first major impetus for its use lies in the belief that this increased flexibility is associated with increased interest and motivation since learners are involved in decision-making processes (Alexander and Jetton 2003), although research in the cognitive and learning sciences reveals that that this is not always the case since metacognitive and self-regulatory skills are required in order for learners to successfully benefit from hypermedia. Second, hypermedia environments are expected to enhance the opportunity to adapt learning to one's personal preferences and cognitive needs. Third, hypermedia's high level of learner control includes affordances for active and constructive information processing; and, finally, hypermedia environments, due to their high level of learner control, are assumed to foster the acquisition of self-regulatory skills in that learners are continuously forced to decide between different information sources (e.g., which hyperlink they should follow next or whether to retrieve pictures or animations in addition to which texts to read) and to evaluate whether the information that they just retrieved helps them to achieve their learning goals (see Astleitner and Leutner 1996, on learning strategies to reach different goals of learning with unstructured hypermedia). Scheiter and Gerjets (2007, p. 288) state that enabling the acquisition of such meta-skills during learning is "one important criterion that learning environments for self-regulated learning may have to meet."

Despite the panacea of hypermedia learning environments, there are many potential pitfalls that must be considered in terms of the role of metacognition and self-regulation with hypermedia learning. While, on the one hand, these environments may come along with all the benefits proposed before, they only do so once certain issues are addressed. With regard to metacognition, Azevedo (2005) states that hypermedia environments, despite their educational potential, have failed to enhance students' learning because students often lack key self-regulatory and metacognitive skills and thus struggle with the open and in itself complex nature of hypermedia learning environments. More specifically, learners do not spontaneously deploy monitoring processes like feeling of knowing (FOK; linking the current content found in the hypermedia environment with their prior knowledge) or judgment of learning (JOL; assessing their emerging understanding of the content). They do not always plan their learning by creating relevant subgoals or activating their prior knowledge. Another important issue is that they tend not to use effective strategies such as making inferences, coordinating informational sources, or engage in knowledge elaboration. These activities, however, are seen as central in hypermedia learning. Following his own criticism with regard to existing hypermedia research which, according to Azevedo and Witherspoon (2009), has not yet addressed how exactly a learner regulates his or her learning with hypermedia, the authors introduce a model which is adapted from self-regulated learning research and allows a more direct view on the interplay between learner characteristics, cognitive processes, and system structure during hypermedia learning.

In line with other SRL researchers (Winne and Hadwin 2008), Azevedo (2005) sees self-regulated learning with hypermedia as a constructive process highlighted by several learning phases and cycles of metacognitive monitoring and control. Azevedo also proposes SRL as being a multiphase process where learners need to:

– Analyze the learning situation
– Set meaningful learning goals
– Determine which strategies to use and assess whether these strategies are effective to meet the learning goals
– Monitor and evaluate their understanding and, if necessary
– Modify plans, goals, strategies, and effort in relation to contextual conditions (which include cognitive, motivational, and task conditions)

The model of Azevedo and colleagues (Azevedo 2005; Azevedo and Witherspoon 2009) includes over three dozen self-regulatory processes such as:

– *Planning*, e.g., setting relevant goals, activating prior knowledge
– *Monitoring*, e.g., feeling of knowing, judgment of learning, monitoring progress toward goals
– *Applying learning strategies*, e.g., hypothesizing, coordinating information sources, drawing inferences, summarizing
– *Handling task difficulties*, e.g., help-seeking behavior

In their model, Azevedo and colleagues do not explicitly label any of these variables as "good" or "bad" aspects of self-regulatory learning with hypermedia; however, they report that successful learners regulated their learning by using effective strategies, planning their learning by creating subgoals, activating prior knowledge, monitoring emerging understanding, and by planning their time and effort. On the other hand, less successful learners tended to use effective as well as ineffective strategies equally often, planned their learning by using subgoals and recycling goals in working memory, and handled task difficulties and demands through engaging in help-seeking behavior. In line with this, several researchers (for an overview, see also Opfermann 2008) have found that learners who possess sophisticated self-regulatory skills are better able to cope with the demands imposed by the complex and multifaceted structure of hypermedia environments. A main difference between successful and unsuccessful learners seems to be that the latter do not seem to deploy the key metacognitive and self-regulatory processes on their own.

Important Scientific Research and Open Questions

Based on the above-mentioned considerations, several attempts have been made to support hypermedia learning by various means of instructional support. For instance, Stadtler (2006) and Opfermann (2008) let students watch a metacognitive modeling video prior to learning with their respective hypermedia environments. In these videos, an exemplary good learner showed how to optimally navigate through an environment in a systematic fashion, how to compare pieces of information from different sources and how to evaluate one's own learning progress and, if necessary, how to adapt one's own way of learning. Other researchers in the field of hypermedia learning (e.g., Bannert 2006) or other types of open learning environments (e.g., Thillmann et al. 2009) worked with several kinds of reflection prompts that aimed at scaffolding students' self-regulated learning process either before or during learning. Finally, authors such as Schmidt and Ford (2003) tried to induce metacognitive activities by presenting direct metacognitive instruction prior to the learning phase (e.g., how important it is for one's own learning to monitor the own learning progress, to reflect upon what one is doing, etc.).

So far, efforts to provide metacognitive support have produced mixed results. On the one hand, students who make use of these support features obviously outperform those who do not with regard to learning performance and learning transfer. But the ability to use such support effectively, in turn, was primarily found for learners with high prior knowledge or expertise, respectively. In line with this, Schnotz et al. (2005) assume that to benefit from instructional support during computer-based learning, learners should possess certain prerequisites; otherwise such support might lead to cognitive overload which may interfere with one's ability to self-regulate.

At first sight, it seems somehow counterintuitive that metacognitive support is only useful for learners who already possess knowledge and metacognitive abilities. Isn't it more logical that learners who lack such abilities receive support to optimize their learning? And if so, how can it be assured that learners with little prior knowledge and little metacognitive abilities benefit from support features such as prompting? According to Schnotz et al. (2005), an important aspect for this group of learners is the *optional use* of support, i.e., giving students the freedom to decide if and when they retrieve instructional support. In order to enable students with low prior knowledge to benefit from metacognitive support, Azevedo and Witherspoon (2009) and Bannert (2006) emphasize the need of extensive metacognitive training for such learners to help them acquire, practice, retain, and learn to apply self-regulatory processes and therefore become more sophisticated learners who demonstrate gains in conceptual understanding and transfer their SRL skills and knowledge. In line with this, Azevedo and Witherspoon (2009) found that training students how to regulate their learning according to models of self-regulated learning (e.g., planning, monitoring, and strategic proceeding) led to greater shifts in mental models, higher posttest performance, and higher metacognitive activities such as prior knowledge activation, planning, or monitoring progress toward goals.

Taken together, these results (cf. Bannert 2005) seem to indicate that the issue of metacognitive support should be addressed from two perspectives. In particular, extensive, long-term metacognitive training as a form of direct metacognitive support should be distinguished from indirect support such as metacognitive prompts. While the first form of support is deemed adequate and necessary for students lacking metacognitive competence, the second support form might be rather suitable for students already possessing metacognitive skills but not being able to display them spontaneously. Most research investigating the impact of metacognitive support for web-based and hypermedia learning has made use of the latter option – mainly because time restrictions of the short-termed studies do not allow for extensive training, but also because participants in these studies are often university or high school students for whom a certain degree of metacognitive skills is presumed. On the other hand, research in the field of self-regulated learning from expository texts in high schools shows that even short-term trainings of metacognitive skills, aligned with cognitive learning strategies, can be very effective (e.g., Leutner et al. 2007).

In addition, and to conclude this chapter, it may also be assumed that sophisticated self-regulatory skills are necessary but not sufficient for hypermedia learning (Scheiter and Gerjets 2007). More specifically, motivation and interest might also be prerequisites that strongly influence how much effort someone invests in the resource-demanding activation of sophisticated self-regulatory and metacognitive learning strategies. Future research should therefore include motivational variables as well.

Cross-References

▶ Interactive Learning
▶ Interactive Learning Environments
▶ Metacognition and Learning
▶ Multimedia Learning
▶ Self-regulated Learning
▶ Situated Prompts in Authentic Learning Environments

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Metacognition and Learning

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Synonyms

Metacognitive control; Metacognitive learning; Meta-learning; Meta-thinking; Self-regulated learning

Definition

Metacognition is generally understood as the ability to contemplate one's own thinking, to observe oneself when processing cognitive tasks, and to organize the learning and thinking processes involved in these tasks. In psychological terms metacognition includes

1. *Metacognitive knowledge* (what one knows about one's own knowledge and behavior)
2. *Metacognitive skills* (how one behaves or acts in relation to a given task) and
3. *Metacognitive experiences* in terms of a cognitive and/or emotional judgment of one's present situation

Metacognition is dependent on general intellectual abilities which are developed over long periods of time on the basis of confrontations with many different kinds of problems. From a metacognitive point of view, learners are managers of their own general and specific knowledge. However, not only do they have to possess the domain-specific and general knowledge relevant for learning transfer, they also have to know how to apply this knowledge in the context of new problems.

Theoretical Background

Referring to Piaget's genetic epistemology and seminal work on intellectual development, the concepts "metathinking" and "metacognition" became a topic of scientific discussion at the end of the 1970s. Developmental psychologists, such as Flavell (1977), observed that children who were well advanced in their intellectual development differed from less well developed children, among other things in their abilities of self-observation in learning. Somewhat later, researchers were able to demonstrate that this is also true of adults. Regardless of their age, good problem solvers observe themselves when processing cognitive problems and develop their own explanations for solutions.

Characteristics of Metacognitive Learning

Metacognition was originally understood as the ability to observe (*monitor*) one's own learning, to evaluate it, and to outline a plan of action to solve a problem (Flavell 1979). The basis of this theoretical concept of metacognition is the idea of contemplating one's own thinking. Metacognitive learning is founded on a person's mental representations and requires two main components (Everson and Tobias 1998):

1. *Metacognitive knowledge*, which operates according to a person's world knowledge; which is concerned with numerous cognitive tasks, goals, actions, and experiences and includes empirical knowledge or convictions about four general factors: (a) knowledge about the nature of one's own information processing (or that of another person), (b) knowledge about learning tasks and their specific requirements, (c) knowledge about cognitive strategies to fulfill these requirements and learning tasks under changeable conditions, and (d) knowledge about the goals achieved through the learning tasks.

2. *Procedures and strategies* to regulate and control the cognitive processes which need to be carried out to process learning tasks successfully. This component, also known as *metacognitive control*, has always been the main focus of research on metacognition. Active monitoring and goal-directed regulation and instrumentation of cognitive processes are seen as central characteristics of metacognition. Central aspects of metacognitive control thus include testing, planning, selecting, making inferences, self-questioning and introspection, and the interpretation of current learning experiences – or also simply determining what one knows about a problem. The important thing about this component is that both cognitive strategies and metacognitive strategies are necessary for the successful processing of a learning task: The former help the learner to progress toward a goal while the latter allow the learner to monitor and control his or her progress on the task.

Corresponding with the distinction between declarative and procedural knowledge metacognitive knowledge may also be separated into two main classes:

- *Declarative metacognitive knowledge* includes knowledge about one's own thinking and that of other people as well as knowledge about demands on one's own cognition.
- *Procedural metacognitive knowledge* refers to the control and regulation of the execution processes involved in carrying out learning tasks.

Interestingly, some researchers (for instance, Bielaczyc et al. 1995) often see a close relationship between the self-explanations of learners and their performance in solving problems. This highlights the confession that metacognition refers to thought processes which are executed under the constant control of consciousness and involve mental representations of one's own action in the world of objects and events. In addition, most researchers agree that metacognition has less to do with personal thoughts about one's own knowledge states and cognitive abilities than with one's conscious determination of emotional and motivational states in carrying out cognitive tasks (Mayer 1998). Specifically, metacognition is said to include the following components:

- *Self-efficacy*, which involves asking oneself questions such as "What do I actually know? How do I think and why do I apply knowledge or strategies?"
- *Self-management*, which has to do with the effective organization and instrumentalization of cognitive and metacognitive processes, and
- *Self-evaluation*, which involves being conscious of one's motivational and emotional states in processing a problem.

These components condition not only the acquisition of new strategies and how they are applied to new problems but also the quality of one's thoughts about oneself.

Important Scientific Research and Open Questions

Research on metacognition was initially stimulated by studies in developmental psychology which demonstrated that people of various ages are capable of applying consciously particular strategies to solve cognitive tasks and of affirming the effectiveness of these strategies through reflection. Remarkably, the concept of "learning strategies" also supports the assumption that humans possess metacognitive abilities: Theorists in this field see the choice of a learning strategy as being primarily dependent on a person's preferences in learning situations (e.g., "holist vs. serialist learning and retention," "certainty vs. uncertainty orientation"). Friedrich and Mandl (1992) differentiated between four general learning strategies which presuppose mostly metacognitive processes:

- *Repetition strategies* (active repetition of learned information)
- *Elaboration strategies* (the creation of relationships with previous knowledge with the help of examples, analogies, mnemotechniques, and visualizations)
- *Organization strategies* (semantic classification and reduction of the amount of information, e.g., through the creation of a diagram) and
- *Control strategies* (monitoring and control of execution through metacognitive control)

A central question of research on metacognition is when and under what conditions do people use their metacognitive knowledge and how does this influence the organization and management of their learning processes? It is not easy to provide a conclusive answer to this question, since there is as yet no precise definition of the processes people use to control their learning. Nevertheless, most theorists agree that metacognition has to do with self-regulated learning which can be characterized at the very least by the following elements (Zimmerman 1986):

- The learning situation must allow for an independent determination of learning goals, times, and methods, that is, the freedom to make individual decisions must be incorporated into the learning situation so that the learner is free to determine his or her own course freely and to search for opportunities to do so.
- The learning situation must always include the possibility of self-instruction, that is, it must provide the informational resources necessary to process the task.
- In learning acts, the individual must have the feeling that he or she is creating something independently. Self-strengthening is thus a central moment of self-regulated learning.
- Finally, the learning situation must allow for the selective application of learning strategies.

Accordingly, self-regulation can be paraphrased as self-created thoughts, feelings, and actions in the pursuance of learning goals. People who regulate their learning effectively are described as proactive learners. They can process cognitive tasks on their own initiative and with creativity, persistence, and a sense of responsibility. However, this requires high learning motivation as well as the skill of self-regulated learning. Most models of self-regulated learning thus include motivational variables (e.g., goals, self-belief, and intrinsic interests) as central elements (Zimmerman 1998). In particular, it is assumed that people use three types of strategies to control their learning:

- Metacognitive strategies
- Motivational strategies (e.g., amount of effort necessary to master a task) and
- Behavioral strategies to create a favorable learning environment

The *metacognitive strategies*, which are the main focus in the current entry, include goal setting, independent organization of information, self-observation, and self-judgment. To gain a better understanding of the special role of metacognitive strategies, it will be useful to first outline the decisive dimensions of the self-regulation of learning processes. To do this, we can refer to Zimmerman's (1998) suggestion of specifying the psychological dimensions and the essential attributes of self-regulation and control by asking the questions *why, how, when, what, where, and with whom* one is learning or is to learn. It is assumed that people use all of their metacognitive knowledge about cognitive, motivational, and environmental strategies to regulate and control their learning. In this way, they choose the learning strategy which seems most suitable for dealing with the learning task at hand. Metacognitive knowledge about the operations and processes necessary to solve a cognitive problem manifests itself in the learner's strategic control of the processes he or she carries out. As the learner contemplates the learning process, he or she acquires additional metacognitive knowledge about tasks as well as additional self-knowledge. This new knowledge is then available for the processing of future learning tasks. The way in which subjective judgments and reactions to learning performance differ from person to person is significant not only from a cognitive and motivational point of view; it also forms the framework for additional observations of one's own behavior and that of others. At the outset, self-regulated and controlled learning requires for the learner to be capable of taking alternatives into account in order to autonomously shape the learning process or individual phases of the learning process. Moreover, the learner must also be capable of deciding between these alternatives.

Various authors (e.g., Simons 1993) see an important link between metacognitive learning and metacognitive control as consisting in *introspective reflection* since learners' contemplation of their own learning process leads to changes in their future information processing and to additional metacognitive knowledge about learning. As the connecting link between thinking and acting, reflection – understood here as observation of one's own thoughts and actions in processing cognitive tasks – provides far-reaching information on the effectiveness of particular learning strategies. It thus provides a basis for the learner to derive general *strategic knowledge* from specific learning activities.

Reflection makes it possible for learners to apply their metacognitive knowledge about tasks, themselves, and strategies during each phase of the control process – that is, during planning, monitoring, and evaluating. Reflection enables learners to consider plans before applying them to a task in a particular learning situation, and it also enables them to control the progress of the learning process and make changes in their plan for finding a solution. Whereas metacognitive knowledge may be seen as static knowledge which includes the strategy variables relevant for processing tasks, reflection may be understood as an active process of exploration and discovery.

The idea that people observe and control themselves when working on cognitive tasks was introduced to pedagogy by Dewey (1933), who argued that we learn more by contemplating our experiences than we do through concrete experience itself. According to Dewey, reflection is the hallmark of intelligent behavior because it is conducive to effective problem solving and improvements in the effectiveness of learning. On the basis of this idea, Smith (1991) concluded that we *learn to learn* as soon as we become conscious of ourselves as learners.

In talking about reflection, it is important to differentiate between reflection on the past and reflection on the present, that is, between contemplation *about* acting and contemplation *while* acting. This distinction is useful for characterizing the specific type of reflective thinking that is going on at various steps in the learning process. Up to this point, our discussion has been valid for both types of reflection. We dealt with contemplation about completed learning as an active process of making sense of previous experience to prepare oneself for future thoughts and actions. This type of reflection allows people to extract meaning from previous experience. Contemplation while acting, on the other hand, refers to the three components of self-regulation – planning, monitoring, and evaluating – and can be understood as the way in which people manage their learning progress by continually adapting their cognitive processing to new information. Reflection may thus consist in contemplation of recent experience or in some cases even in anticipation of future experience.

For educational practitioners the discussion of metacognitive thinking essentially boils down to the question of how one can teach school children to “learn how to learn” (Hacker et al. 1998). It is a common belief that education and teaching should do more than teach children subject matter and help them to develop specific skills. In addition, educators argue that school children should also learn to take responsibility for their learning at and away from school. It is also said that metacognitive learning takes place each time a person acquires a strategy to make learning, information processing, or problem solving easier. Ideally, metacognitive learning should consist of the acquisition of strategies to be applied at any stage of development and to any cognitive challenge. However, it is unlikely that universal learning strategies of this type exist.

Cross-References

► Learning Strategies
► Learning to Learn
► Metacognition and Hypermedia Learning
► Metacognitive Aspects of Experiential Learning
► Metacognitive Learning: the Effect of Item-Specific Experiences
► Metacognitive Strategies
► Mnemotechnics and Learning
► Self-efficacy for Self-regulated Learning
► Self-regulated Learning

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M

Metacognitive Control

► Metacognition and Learning

Metacognitive Control of Learning Strategies

► Metacognitive Control Over the Distribution of Practice: When is Spacing Preferred?

Metacognitive Control Over Spaced Practice

► Metacognitive Control Over the Distribution of Practice: When is Spacing Preferred?

Metacognitive Control Over the Distribution of Practice: When is Spacing Preferred?

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Synonyms

Metacognitive control of learning strategies; Metacognitive control over spaced practice

Definition

Metacognitive knowledge refers to our knowledge of our own knowledge and of the way in which our cognitive processes work. Control over the distribution of practice refers to using our metacognitive knowledge to decide how to schedule study or practice opportunities over time. Practice is massed when the same information or activity is studied or practiced two or more times in immediate succession. Practice is distributed or spaced when successive study or practice opportunities are separated by time and, usually, by other events. Thus, metacognitive control over the distribution of practice concerns whether learners will choose spacing or massing when they schedule their own study or practice time and how metacognitive knowledge contributes to their decisions.

Theoretical Background

Scientific thinking about metacognition as it relates to learning has been strongly influenced by a theoretical framework articulated by Nelson and Narens (1990). According to this view, we can monitor the current state of our knowledge, representing it at a higher meta-level. This meta-level also includes knowledge of how cognitive processes function and information about the current learning context. Thus, the meta-level allows one to control the learning process by formulating strategies designed to achieve one's goals, taking into account the judged level of one's current learning, one's beliefs of how cognitive processes work, and current task constraints.

When scheduling one's own practice, a strategy of spacing practice would seem to be optimal. There is an extensive research literature indicating that spaced practice generally leads to greater learning and memory than the same amount of massed practice. However, it does not necessarily follow that people will use such a strategy. Studies that have systematically varied the distribution of practice have found that learners sometimes err by thinking that they have learned as much or more from massed as from spaced practice. Metacognitive theories of how learners schedule their practice differ in the degree to which learners are assumed to have knowledge of the superiority of spacing over massing.

One theory that assumes knowledge of the benefits of spacing was inspired by the discrepancy-reduction model which has been an influential theory in other domains of self-regulated learning. The model's basic assumption is that learners evaluate how well they have learned different elements of information and then allocate their resources preferentially to learning the information they know least in order to reduce the largest discrepancies from a desired or target level of learning. As modified to apply to the distribution of practice (Benjamin and Bird 2006), the model suggests that learners will preferentially apply the more effective strategy (spaced practice) to the information that is least learned and, thus, needs its benefits most. This implies that learners have at least a tacit understanding that spaced practice is superior.

Similar knowledge of the benefits of spaced practice is implied by the adaptation of another existing theory of self-regulated learning called the agenda-based-regulation model. According to this model, learning is goal directed. To-be-learned information is prioritized in relation to one's goal on the basis of a variety of factors, including the difficulty of learning, the time available for learning, and the reward structure of the task. As adapted to apply to the distribution of practice (e.g., Toppino and Cohen 2010), the more effective learning strategy (spacing) will be used preferentially to learn information that is judged to have the highest priority for attaining the goal. (It should be noted that, in a situation in which more difficult-to-learn items of information are given the highest priority, this hypothesis may be functionally indistinguishable from the discrepancy reduction hypothesis.)

In contrast to the above hypotheses, Metcalfe (2009) assumed that learners have no metacognitive knowledge of the superiority of spaced over massed practice. Learners are thought to monitor the rate at which they are learning. If the rate of learning is high at the end of a study period, indicating that learners are still making substantial progress, they will opt to continue studying by choosing massed practice. If the rate of learning has declined substantially so that learners are not making progress at the end of a study period, they will choose to stop studying, at least for now. This leads to spaced practice if the information is studied again at another time. The important point is that a choice of spacing does not indicate implicit knowledge that spacing is better than massing. It is simply the default outcome of choosing to stop studying at this particular time.

Finally, Son (2004) offered a hypothesis that falls somewhere between the previously discussed theories. She assumes that learners monitor how well they have learned. If they judge some information to be relatively well learned at the end of a study period, spacing should be the preferred strategy because little more would be learned by continuing to study. However, if learning were judged to be poor at the end of a study period, learners should opt to mass practice because, otherwise, what was learned might not survive the interval until the next study period. Thus, Son's hypothesis seems to imply that learners believe the relative benefits of massing and spacing practice to vary depending on how well the target information has been learned.

Important Scientific Research and Open Questions

Initial research on the metacognitive control over the distribution of practice seemed to support the hypotheses of Son (2004) and Metcalfe (2009). In a study of vocabulary learning (word pairs) involving a brief initial study opportunity, Son found that learners' preference for spaced practice relative to massed practice was greatest for items that they judged to be easiest to learn and declined with increasing item difficulty. Subsequent research indicated that these findings were attributable to the fact that harder-to-learn items were also harder to initially encode or perceive. When learners failed to encode or perceive a pair, they wanted to see it again right away (massed presentation). This inflated the tendency to choose massed practice for more difficult pairs. When further research eliminated the correlation between the difficulty of initial encoding or perception and the difficulty of learning pairs, a very different pattern of results was obtained. Under these circumstances, the results consistently indicated that the preference for spaced practice relative to massed practice was least for the easiest-to-learn pairs and greatest for the most difficult pairs. This pattern of results is consistent with the discrepancy reduction hypothesis. It also is consistent with the agenda-based-regulation model, provided that we assume that difficult-to-learn items are given the highest priority when there is no other obvious basis for assigning priorities.

Finally, in a recent experiment by Toppino and Cohen (2010, Experiment 3), point values (1 vs 5 points) were assigned randomly to pairs. Learners were told that the points represented the value of remembering a pair on the final recall test. Their goal while studying should be to get the highest point total possible on the final test. Results revealed that learners preferred spaced practice for 5-point items more than for 1-point items, and, under these circumstances, the difficulty of learning the items played a reduced role. These results are primarily supportive of the agenda-based-regulation hypothesis because spacing was preferentially used for the pairs that would contribute most to a high score on the final test. More generally and perhaps most importantly, these results strongly imply that learners do have at least implicit knowledge that spaced practice is more effective than massed practice.

A number of important questions remain unresolved. First, do learners, in fact, have knowledge that spaced practice is superior to massed practice? The tentative conclusion that they do is inferred from their pattern of choices when they are allowed to choose between massed and spaced practice. Converging evidence, especially evidence based on a more direct assessment of learners' metacogntive knowledge, is needed before the matter can be considered settled. Second, to the extent that learners appreciate the relative advantage of spaced practice, what do they actually know? To date, all studies have given learners two options: massed practice and spaced practice. Thus, a preference for spaced practice could indicate a metacognitive understanding that spacing helps or an intuition that massing will not be helpful. A related question concerns whether learners understand, in a comparison of two levels of spaced practice, that greater spacing will usually lead to better learning and memory. Third, learners may have a metacognitive understanding of the advantage of spaced practice relative to massed practice, but they almost always opt for massed practice for some to-be-learned items. Why do they not maximize their learning by always choosing spaced practice? Fourth and finally, very few studies have systematically examined learners' metacognitive control over the distribution of practice, and they all have used very similar methodology. Is it possible that the results are limited to the paradigm that has been used? For example, one characteristic of the studies that have been conducted so far is that the second study opportunity for spaced items occurs closer to the test than the second study opportunity for massed items. Could the apparent preference for spacing actually be a preference for a short retention interval? Some indication that this is not the case comes from an experiment by Toppino and Cohen (2010, Experiment 2) in which the typical pattern of preference for spacing was obtained, even though the retention interval advantage for spaced items was greatly reduced and made much less obvious to the participants of the study. Nevertheless, the question has not been definitively resolved.

Cross-References

- ▶ Metacognition and Learning
- ▶ Metacognitive Experiential Learning
- ▶ Recall and Effect of Repetition on Recall

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Metacognitive Experiential Learning

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Synonyms

Learning how to learn

Definition

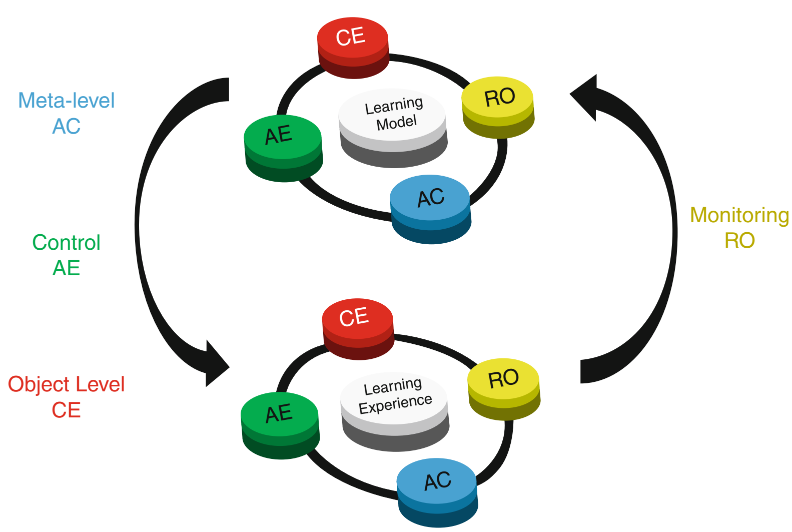
Metacognitive experiential learning is the process by which individuals understand the ways they learn from experience and themselves as learners and use that understanding to improve their learning effectiveness.

Theoretical Background

William James (James 1890) was the originator of the idea of metacognitive experiential learning. In the chapter on will in his famous *Principles of Psychology* James developed a theory of intentional action which is essential for any metacognitive knowledge to be useful in improving one's learning ability. His ideo-motor action theory states that an idea firmly focused in consciousness will automatically issue forth into behavior. In the early twentieth century William James' emphasis on the role of intentional conscious experience in learning was eclipsed by the advent of Watson's behaviorism and the desire of psychology to become an objective science untainted by subjectivism. The prohibition of any role for consciousness in human learning theories was to continue for over 50 years. Flavell's (1979) introduction of the concept of metacognition reintroduced consciousness to the study of human learning and stimulated a vigorous stream of research. His classification of four categories of metacognition has guided this work – metacognitive knowledge (e.g., "I am not as good at math as others are."), metacognitive experience (e.g., feeling that learning something is hard and frustrating), goals (e.g., a goal to learn how to speak a foreign language), and strategies (e.g., cognitive or behavioral actions taken to achieve learning goals). He divides metacognitive knowledge into three sub-categories: knowledge of person variables, task variables, and strategy variables. Knowledge of person variables refers to general knowledge about how human beings learn and process information, as well as individual knowledge of one's own learning processes. Task variables include knowledge about the nature of the task and what it will require of the individual. Finally, knowledge about strategy variables include knowledge about ways to improve learning as well as conditional knowledge about when and where it is appropriate to use such strategies.

More recently, Nelson (1996) and his colleagues have developed a model that emphasizes processes of monitoring and control in metacognition. An individual monitors their learning process at the object level and relates the observations to a model of their learning process at the meta-level. The results of the conscious introspection are used to control actual learning at the object level. Until now, research on metacognitive learning has explored the influence of only relatively simple models of learning. For example, a study of fifth grader self-paced learning of stories found that the best students spent more time studying difficult versus easy stories, while there was no difference in study times for the poorer students. The findings suggest that the poorer students lacked a metacognitive model that dictated a strategy of spending more time on difficult learning tasks.

Experiential Learning Theory proposes that by using a model based on experiential learning theory, learners can better understand the learning process, themselves as learners and the appropriate use of learning strategies based on the learning task and environment. This suggests a modification of Nelson's metacognitive model as shown in Fig. 1. Here, an individual is engaged in the process of learning something at the object level of direct concrete experience. His reflective monitoring of the learning process he is going through is compared at the abstract meta-level with his idealized experiential learning model that includes concepts such as: his self identity as a learner, knowledge of whether he is spiraling through each stage of the learning cycle, the way his unique learning



Metacognitive Experiential Learning. Fig. 1 Nelson's metacognitive model modified to include the experiential learning model style fits with how he is being taught, and the learning demands of what he is learning. This comparison results in strategies for action that return him to the concrete learning situation through the control arrow.

Important Scientific Research and Open Questions

Current research on metacognitive experiential learning seeks to answer a number of questions such as: How does awareness of the various components of a person's metacognitive learning model such as their learning style, learning identity, and array of learning strategies influence learning effectiveness? How does learning style influence metacognitive activity, for example, are reflective learners better at monitoring their learning process?

Cross-References

- ► Experiential Learning Space
- ► Experiential Learning Spiral
- ► Experiential Learning Theory
- ► Kolb's Learning Styles
- ► Learning Identity
- ► Learning Style
- ► Metacognition and Learning

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Metacognitive Judgments

► Confidence Judgments in Learning

Metacognitive Knowledge

► Beliefs About Language Learning

Metacognitive Learning

► Metacognition and Learning

Metacognitive Learning Strategies

Methods or techniques intentionally used by learners that generally include planning, monitoring, and regulating learning.

Metacognitive Monitoring

► Comprehension Monitoring

Metacognitive Monitoring and Control

► Metacognition and Hypermedia Learning: How Do They Relate?

Metacognitive Processes in Change and Therapy

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Synonyms

Cognition about cognition; Hypercognition

Definition

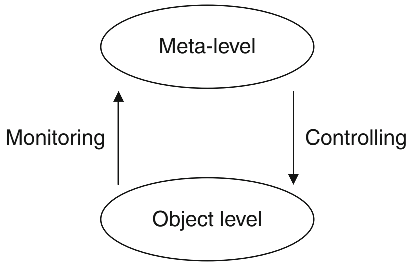
Cognition is a Latin term, *cognoscere*, meaning "to know." It covers the process of thought and involves various modes of knowing, such as perceiving, remembering, imaging, conceiving, and judging.

Metacognition is defined as cognition about cognition, and refers to cognitive processes that are involved in appraisal, monitoring, or control of cognition (Flavell 1979).

Theoretical Background

J. Flavell used the term "metacognition" very early referring to modeling the children's cognitive development (Flavell 1979). The concept of metacognition is used to model artificial intelligence, but also as a term in the study of neuropsychology and aging (Metcalf and Shimamura 1994). In experimental psychology and neuroscience the concept of metacognition has been used to study the distinction between monitoring and control. Monitoring is referring to the appraisal about one's mental capacity and strength of one's memories (Nelson and Narens 1990). The other part of the metacognition involves the active control over the thinking processes and the regulation of the monitoring and plans. Monitoring and control seem to be based in the prefrontal cortex and thus seem to be acquired skills. Nelson and Narens have proposed that cognition can be divided into two inter-related levels, the meta-level and the object level. The former is defined as the cognition about cognition (monitoring and controlling one's thoughts) and the object level refers to the general thoughts about objects (Wells 2000) (Fig. 1).

The distinction between metacognition and cognition has been applied to understand the mind as a dynamic self-regulatory executive functional system and to inform the role of cognition in psychological disorders (Wells and Matthews 1994). More recently, metacognition has become a crucial element in



Metacognitive Processes in Change and Therapy. Fig. 1 Cognition: The flow of information between meta-level and object level (From Nelson and Narens 1990)

metacognitive models and treatment of psychological disorders (Wells 2000; Wells 2009).

The concept of metacognition has at least three facets, which is crucial in understanding psychological problems. First, metacognition comprises knowledge, which is beliefs about one's own ability to control thoughts or memory. Metacognitive knowledge is the information the individual has about their own cognition, such as what is the most useful to pay attention to and how best to remember an important piece of information (learning strategies). Second, metacognitive strategies and regulation refers to the executive functions the person uses in the allocation of attention, monitoring information, planning, and detection of errors in one's performance. Metacognitive experience is a subjective experience of knowing something without being able to retrieve the information from the brain. An example of metacognitive experiences is the so-called tip of the tongue phenomenon, a feeling of knowing experience, which is often experienced as a mildly aversive state leading to the continuation of the retrieval efforts.

In the Metacognitive Therapy developed by A. Wells (2000, 2009), the distinction between meta-level and object level is at the core of the understanding of psychological disorder. The model proposes that the patients suffering from psychological disorders are in predominantly an object mode of cognition and do not have the resources, cognitive flexibility, or the knowledge to process information in the metacognitive mode. Thus the thoughts and reality are mixed up in a biased way and the person is vulnerable for adversities and emotional problems. The aim of Metacognitive Therapy is to help the person acquire metacognitive processing skills, which involve: (1) a metacognitive perspective and mode of processing, (2) attentional capacity and biases, and (3) flexible control of thoughts and information processing. Psychological disorders are characterized by inflexible preservative processing styles, such as worry or rumination and threat monitoring strategies that sustains the emotional problems. A healthy mental functioning is associated with flexible shifting between modes when this is necessary. An example is that when appraisal of danger is unrealistic and threat does not exist, object mode cognitions are counter-productive for change. In contrast, if there is real threat to the person, the object mode processing of the threat is adaptive and has survival value.

To describe the metacognitive skills and aims in more detail: Becoming aware of the metacognitive perspective involves that the patient is able to examine his thoughts and beliefs in a detached way and treat them as interpretations and not as real depictions of reality. Furthermore, attention seems to have an executive organization facility that directs the mind's attention to a new context by blocking out information. Attentional bias is seen in all psychological disorders, and in emotional disorder it refers to the selective attention on personally relevant threatening information. In psychological disorder the attention is mainly turned inward, on one's thoughts and sensations, and this strengthens the focus on self-referent information on the cost of paying attention to the social surroundings. Thus, when attention is allocated outward this is associated with a healthy functioning. It is a major target in MCT to develop new plans and ability to allocate attention externally to the actual situations and to the context of the individual, which have adaptive value.

Moreover, a crucial goal in MCT is to help the person acquire a flexible control of thoughts, which implies that the person may become aware of the style and content of one's own thinking. For instance, in a metacognitive mode a person will be more aware of his or her repetitive style of thinking, such as worries, and recognize it as a pattern of thinking and learn to detach from that instead of doing the reality testing of the content of the worry (object level).

Important Scientific Research and Open Questions

There are compelling evidence of support for the role of worry, rumination, and an excessive tendency to focus on threat for emotional disorders (Wells 2009). The perseverative styles of thinking, such as worry and rumination seem to have negative consequences for adaptive emotional self-regulation and mental health. It is found that change in metacognition is associated with treatment outcome in anxiety disorder over and above cognition, implying that change in the metacognition is more important for the outcome. Also the effects of MCT have been shown in many open trials, demonstrating reliable improvement or recovery during treatment and follow-up. The effects of MCT seem to be consistent across a range of disorders, which indicate that the treatment is generalizable to a variety of disorders. Furthermore, the treatment has recently been tested against wait-list controls, applied relaxation and cognitive behavioral therapy in randomized controlled trials (RCT) of various anxiety and depressive disorders. Here the MCT came out favorably, but there are still too few RCTs that have been conducted with MCT, so there is a need for more comparisons and studies of long-term effects.

Cross-References

► Metacognition and Learning
► Metacognitive Experiential Learning
► Metatheories of Learning

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Metacognitive Skills

► Learning Strategies

Metacomprehension

► Comprehension Monitoring

Metadata

► E-Learning Authoring Tools

Metaknowledge

► Abstraction in Mathematics Learning

Meta-learning

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Synonyms

Adaptive learning; Learning to learn; Planning to learn; Selection of learning methods; Self-adaptive systems; Workflow design

Definition

In general, metalearning can be defined as the study of machine learning and related techniques to induce models of the behavior of decision support methods and exploit them to obtain more efficient solutions.

Here, we focus on a particular approach to the field of metalearning that is concerned with the relation between *problems* or *tasks* and *solutions*. Assume a given task is decomposed into one or more subtasks, each subtask is characterized by a given goal, data, and, possibly, background knowledge. In such case, solutions to some of the subtasks can involve the deployment of learning algorithms and decision support methods. Metalearning associated with one subtask involves meta-level information characterizing the current goal and the given data and exploits meta-level information acquired in past experiments to recommend the best solution for this subtask.

Metalearning associated with a more complex problem may include extra information concerning how tasks may be decomposed into subtasks, description of (partial) solutions of some subtasks and their measure of success in past problems, the ontology of machine learning and decision support operations, description of preconditions and post-conditions for each operator, and methodologies for constructing solutions using planning or adaptation of existing plans.

Theoretical Background

The application of machine learning and other decision support systems to classification and regression tasks has become a common practice, not only in research but also in commerce and industry (e.g., credit rating and fraud detection in finance, medical diagnosis, mine-rock discrimination, etc.). Many successful applications are custom-designed, and the result of skillful use of human expertise, which makes it hard to replicate. Furthermore, there is an ever increasing number of available systems (machine learning and others) which are relatively complex. This problem is aggravated by the fact that many algorithms require parameter settings. An additional factor is that the performance of the algorithms varies on different tasks (problems) and even on a single task, the concept being modeled may change (e.g., as fraudsters adapt to monitoring strategies). Besides, many solutions represent really compositions of steps, such as bagged decisions trees. To maximize performance, systems should be able to adapt to different problem characteristics. The difficulties presented above have led some researchers to explore the area of metalearning, which provides a more principled approach in the search for solutions (Brazdil et al. 2009; Smith-Miles 2008).

Metalearning is associated either with a single subtask, or else, with a more complex problem that can involve more than one subtask. Due to the complexity of the latter case, most work has focused on a single subtask. Each of the two situations is discussed separately in detail below. As most of the work on metalearning addresses machine learning applications, we focus on this kind of task. Other applications are discussed later.

Metalearning Associated with a Single Machine Learning Task

Structure of a System that Exploits Metadata and Metalearning: A metalearning system is essentially composed of two parts. One part is responsible for the acquisition of metaknowledge concerning machine learning tasks, data, and solutions. The other part is concerned with the application of metaknowledge to new problems with the objective of identifying an optimal machine learning algorithm or technique. The latter part – application of metaknowledge – can be used to help to select or adapt suitable machine learning algorithms. So, for instance, if we are dealing with *a classification task*, metaknowledge can be used to select a suitable *classifier* for the new problem. Once this has been done, one can train the classifier and apply it to an unclassified sample for the purpose of class prediction.

Experimentation and acquisition of metadata: One common way nowadays of acquiring metadata relies on experimentation, which can be either controlled by a human or carried out automatically. The latter alternative is nearly always preferred. It gives origin to the so-called experiment databases that can be explored by the whole research community.

To carry out automatic experimentation, we need a pool of problems (datasets) and a set of candidate machine learning algorithms to be considered. Then, we need to define also the experimental method which determines which alternatives should be considered and in which order.

Suppose that at some stage we select a dataset characterized using certain metafeatures, in combination with certain machine learning algorithms. The combination is assessed using an evaluation method (e.g., cross-validation) to produce performance results. The results, together with the characterization, represent a piece of metadata that is stored in the metadata base. The process is then repeated for other combinations of datasets and algorithms.

Various experimentation methods can be used in the process. On one end of the spectrum are *exhaustive methods* that consider all possible alternatives. On the other end of the spectrum are methods that do not carry out all possible experiments, but rather try to determine which experiments are expected to contribute with more information to the metalearning process and, thus, should be carried out first. This is related to various other areas, including experiment design, active learning/testing on meta-level, and model-driven approach to conducting (further) experiments.

Besides, one can generate problems (i.e., metadata) that may help to understand better the areas of the metafeature space which are not well known. For instance, one might be interested in understanding the behavior of a given algorithm on classification tasks that have a varying amount of noise.

Characterization of Datasets: A metalearning approach to solving this problem relies on dataset characteristics or metafeatures to provide some information that would differentiate the performance of a set of given learning algorithms. These include various types of measures discussed in detail below.

Much previous work in dataset characterization has concentrated on extracting statistical and information-theoretic parameters estimated from the training set. Measures include number of classes, number of features, ratio of examples to features, degree of correlation between features and target concept, average class entropy, etc. The disadvantage of this approach is that there is a limit to how much information these features can capture, given that all these measures are uni- or bilateral measures only (i.e., they capture relationships between two attributes only or one attribute and the class).

Another idea is based on what are called *landmarkers* which are simple and fast learners. The accuracy of these simplified algorithms is used to characterize a dataset and to identify areas where each type of learner can be regarded as an expert. An important class of measures related to landmarkers uses information obtained on simplified versions of the data (e.g., samples). Accuracy results on these samples serve to characterize individual datasets and are referred to as *subsampling landmarks*.

Designing metafeatures involves a trade-off between information content and computational cost. Typically, the more informative the measure is, the more computational cost it requires. One particular class of techniques does not acquire the information in one step, but rather uses a kind of *active learning* approach. Some researchers (Leite and Brazdil 2010) have exploited this notion when characterizing the performance of algorithms using samples (i.e., subsampling landmarks). The process of obtaining a characterization is divided into several steps. In each step, a decision is first made as to whether the characterization process should be continued. If the answer is positive, the system determines which characteristics should be obtained in the next step. It was shown that this approach can lead to savings of time, when trying to identify the suitable classification algorithm for a given dataset.

As experiments are expensive to perform and each meta-example requires a number of experiments to be performed, active learning has the potential of significantly lowering the cost of metalearning. Prudêncio and Ludermir (2009) have exploited the notion of classification uncertainty to identify the meta-examples that are most informative. The results suggest that this active learning approach offers some gains over random selection of meta-examples as the error rate decreases faster.

Representation of metadata and metaknowledge: In general, metadata and metaknowledge can be stored either in raw form, in a database, or generalized with the help of a metalearner. If the first alternative is used, the generalization of metadata is done in the application phase. This alternative involves the so-called *lazy learning* method at the meta-level, such as k-NN.

The other group involves learning algorithms whose aim is to generate a generalization model, such as a decision tree or decision rules. This generalization model represents in effect acquired metaknowledge.

In the early days, the metalearning model, composed usually of decision rules, was normally produced manually by the expert researcher. It summarized his knowledge of various machine learning algorithms. As the number of machine learning algorithms has grown, this approach is in general no longer practical.

Employing Metaknowledge to Select a Subset of Machine Learning Algorithms: Metaknowledge is typically used to select a subset of machine learning algorithms. Selection of machine learning algorithms can be seen as a search problem. The search space includes the individual machine learning algorithms, and the aim is to identify either (1) the single best algorithm, or (2) the best algorithm and all algorithms considered equivalent to it, or (3) ranked list of algorithms. The last option involves ordering of different algorithms according to some performance measure (e.g., accuracy, precision, recall, AUC, etc.). Furthermore, it is possible to combine (2) and (3) and return a ranked subset of algorithms.

The search method used in this process can exploit metaknowledge. This is in general advantageous as it often leads to better solutions. Meta-level information involves characterization of the current learning goal (e.g., learn to classify examples and the data). The process exploits meta-level information acquired in past experiments to recommend the best solution for this subtask.

If the system returns a (ranked) subset of algorithms, then the selection process can be repeated. In general, this can be done more than once, and it can be done with the help of meta-level information. If the number of alternatives selected by the metalearning model is relatively small, the system can simply evaluate all the alternatives (e.g., with recourse to cross-validation) in order to select a single best algorithm. We note that metaknowledge does not completely eliminate the need for further search, but rather provides a way to conduct it effectively. The search effectiveness depends on the quality of the metaknowledge.

Role of Metalearning in the Search for Inductive Hypotheses: Metalearning is often seen as a way of redefining the space of inductive hypotheses searched in machine learning and data mining. This issue is related to the idea of *search bias*, that is, search factors that affect the definition or selection of inductive hypotheses (Mitchell 1997). In this sense, metalearning studies how to choose the right bias dynamically, and thus differs from base-level learning, where the bias is fixed or user-parameterized. Metalearning can also be viewed as an important feature of self-adaptive systems, that is, learning systems that increase in efficiency through experience (Vilalta and Drissi 2002).

Employing Metalearning for Algorithm Selection on Different Types of Tasks: While most approaches to metalearning have dealt with the task of selecting machine learning algorithms and, in particular, classification tasks, plenty of work has been done showing how metalearning can be applied to different types of tasks (Smith-Miles 2008). These include other machine learning tasks (regression and time series forecasting) as well as tasks in other research areas (sorting, constraint satisfaction, and optimization). The interest for algorithm selection using metalearning approaches is gaining particular attention in the optimization field. It has been used to address SAT, TSP (Travelling Salesman Problem), and scheduling problems. One example of such an approach is SATzilla.

Transfer of Knowledge among Domains: *Inductive transfer* or *transfer learning* refers to the ability of a learning mechanism to improve performance on the current task (i.e., on the target task) after having learned a different but related concept or skill on a previous task (i.e., on the source task). Transfer may additionally occur between two or more learning tasks that take place concurrently. Recent years have seen an explosion of research tackling the transfer-learning problem from different perspectives. As an illustration, a selective mechanism can decide which instances of the source task can be used for training on the target task; a similar idea is applicable at the feature level, selecting only those features that are most relevant for the target task. Other approaches consist of transferring parameter values from one learning mechanism to another or using the parameters as seed values to optimize the search for optimal parameters on the target task. Finally, there have been attempts to transfer domain knowledge from one task to another, mostly in the form of relational knowledge.

Metalearning Associated with Complex Tasks

More complex problems typically include various subtasks. The overall solution thus needs to include a solution to each individual subtask. The overall solution includes partially ordered sequences of processing steps, which are usually referred to as *workflows*. The objective can be formulated as *workflow design*. This can be done either manually or automatically.

Manual workflow design is usually done with the help of visualization techniques. Many data-mining systems, such as SPSS Clementine, Weka, RapidMiner, or KNIME (among others), include the possibility of composing workflows by dragging in icons representing individual operations. Automatic approaches can use planners to compose workflows. Various techniques are used to make this process feasible and/or faster. The process can be facilitated by exploiting meta-level information.

Meta-level information: As the process of elaborating solutions to complex tasks becomes inherently more complex, we can include different types of information that can facilitate this process, including:

- Information concerning how tasks may be decomposed into subtasks (e.g., the task is decomposed into a preprocessing step, followed by, say, a classification task, as in KDD)
- Description of (partial) solutions of some subtasks and their measure of success in past problems (e.g., solutions that involve *bagged decision trees* worked well in specific circumstances)
- The ontology of machine learning operations that can be used for each particular subtask and description of preconditions and post-conditions for each learning operator (e.g. classification)
- Methodologies for constructing solutions using planning
- Methodologies used for adaptation of existing plans

Various recent data-mining systems include various aspects (but typically not all) mentioned above. Many systems have been proposed, some already about a decade ago – Data Mining Advisor (DMA), MiningMart, and CITRUS. The more recent systems include IDA, Hybrid Data Mining Assistant (HDMA), and NExT, among many others. The issues that concern the designing of data-mining systems capable of resolving complex problems are the object of study in various specialized workshops (e.g., Planning to learn etc.).

Important Scientific Research and Open Questions

When using metalearning for a single subtask, the most important issues are:

- Designing suitable metafeatures with acceptable computational cost
- Gathering a sufficient amount of metadata also with an acceptable computational cost
- Strategies for characterizing machine learning and decision support algorithms on demand

Besides, one important problem that needs to be addressed is how to decompose a (learning) goal into subgoals and selecting suitable (learning) operators for each subgoal, while exploiting meta-level information (as outlined in the previous section) to carry this out as efficiently as possible is one of the most important research issues in machine learning, data mining, and adaptive computing in general.

Cross-References

► Adaptive Learning Systems
► Learning Algorithms
► Multistrategy Learning
► Subgoal Learning
► Transfer of Learning

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Metamemory for Text

► Comprehension Monitoring

Metapatterns for Research into Complex Systems of Learning

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Synonyms

Abduction; Patterns; Systems thinking

Definition

The word *metapattern* was coined by Gregory Bateson (1979/2002, p. 10). According to Bateson a *metapattern* is a pattern of patterns, a vast generalization, and a pattern which connects. In this case, *meta-* refers to the sense of overarching or transcendent. A metapattern is then an overarching or transcendent pattern.

Theoretical Background

The use of "metapatterns" as tools for research into learning, discourse, and cognition is the primary focus of this article. However, such an approach is applicable to a wide range of other phenomena, such as teaching, classroom communities, schooling, policy, and institutional dynamics. Metapatterns are ubiquitous functional patterns or principles that are widely evident throughout the scope of biological evolution, as well as throughout culture, technology, and cognition. From a complexity sciences point of view, metapatterns are the embedded and emergent patterns in the natural world. The extension into culture and technology is a result of this natural, biological origin or convergence.

The core list of metapatterns and some of their key functions and qualities include: (1) *spheres* – containment, strength, equanimity; (2) *tubes* – linear transport or flow, linear strength, connection; (3) *sheets* – capture, two-dimensional movement, maximized surface area; (4) *layers* – organization, stability; (5) *borders and pores* – separation, barrier, regulation of exchange or flow; (6) *centers* – organizational stability, attraction, control; (7) *binaries* – simplest level of complex relationships, pairings; (8) *arrows* – flow, movement, growth, sequences, directional relationships, or connections; (9) *breaks* – change, transformation, divergence, branching; (10) *calendars and time* – a binary of movement and memory, stages, as arrow or cycle, progression; and (11) *cycles* – repetitions, maintaining systems, feedback looping, circulations (Volk 1995; Volk and Bloom 2007).

In addition to these 11 patterns, other possibilities exist and have been identified by other scholars. However, the central characteristics in determining whether a particular pattern or principle can be utilized as a "meta"-pattern are that the pattern appears in multiple contexts or disciplines and it has a set of core functional properties that are useful across scales. Metapatterns, as relatively scale-free principles, concepts, or patterns, can be used to see and explore connections across diverse contexts.

The functional qualities, meanings, and metaphorical aspects of these patterns are of central importance in their use in research and learning. For instance, binaries are the simplest form of complex relationships. The joining or clustering of two or more "things" generates a new whole that is greater than the parts and, at the same time, produces a whole with significant new properties. Binaries are associated with unity or separation, duality, tension, and complementarity.

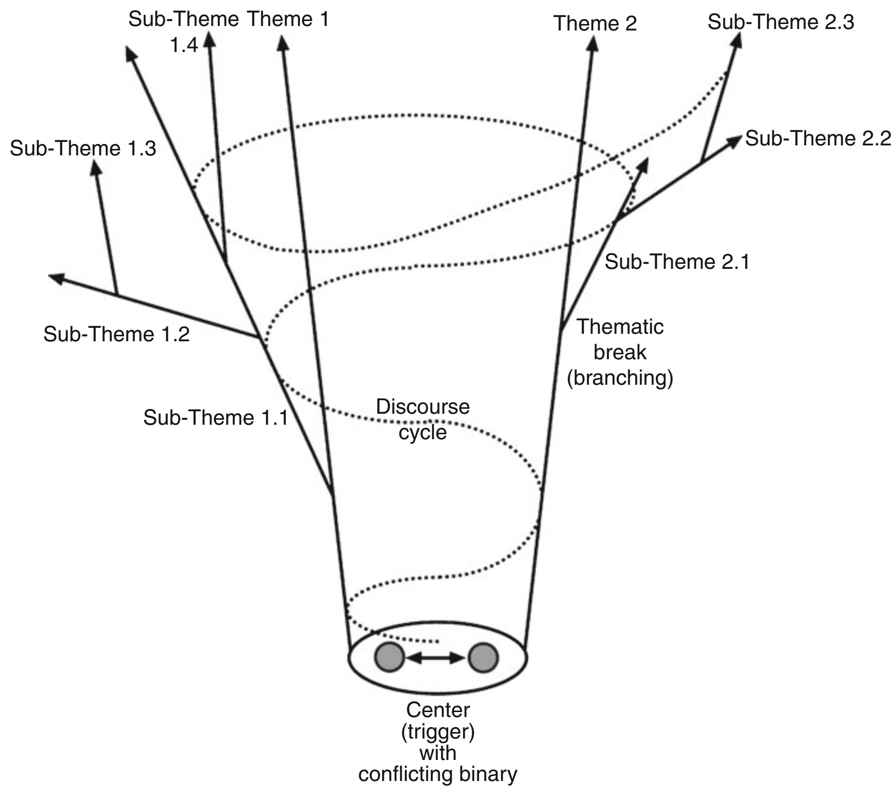
For instance, two senses organs, such as eyes or ears, provide a significant new functionality as opposed to having only one sense organ. Two eyes provide for depth perception and a greater field of vision that is not available with one eye. On the other hand, multiple lenses in the two eyes of a housefly provide the housefly with a greater field of vision (with two eyes) and a vastly increased sensitivity to movement (with multiple lenses).

There are three fundamental uses of metapatterns (Bloom and Volk 2007). The first use focuses on the subject matter of the metapatterns themselves, as well as related scale-transcending principles. Since metapatterns appear across multiple contexts and subject matter disciplines, they can provide a greater sense of relevance, meaning, and interconnectedness of knowledge. Returning to the example of binaries, such functional patterns appear in the arts (e.g., synergy of light and shadow), science (e.g., DNA base pairs, symmetry, positive and negative ions), social sciences (conflict, double binds), mathematics (e.g., numerical systems, positive–negative), literature (e.g., protagonist vs antagonist), and culture (e.g., gods–devils, four directions and their qualities in aboriginal cultures). In each case, the binaries (or larger number systems) create a greater whole with significant new properties or meanings. The development of understandings of such fundamental patterns provides for the ability to transfer knowledge across disciplines. Even though the specific details of each pattern may differ across contexts, the core meaning or functionality is still present.

The second use involves using metapatterns as analytical tools for investigating phenomena with the aim of providing new insights into the structure and dynamics of the phenonmena. Since metapatterns commonly appear throughout and across contexts (from the natural world to technology to culture and to mind), they can be used to identify various patterns and their interconnections and interactions. For example, a video recording of an intense student argument along with a transcript and other observational data can be analyzed using metapatterns, in the following way: *Arrows* can represent the thematic and conceptual development, while *binaries* can be used to represent conflicting points of view. As the conceptual themes develop, they can branch off or *break* into subthemes. Any ongoing phenomena or system must have one or more *cycles* occurring to maintain the system. In an argument, these cycles involve student talk as well as student cognition as they continue to develop their particular conceptual stance. The *triggering* (another possible metapattern) of the argument probably occurs as a conflicting *binary*-based *center*, which consists of some sort of conflicting problem or point of view. Figure 1 shows an example of a metapatterns-based model of a student argument.

The third use involves using metapatterns as design and modeling tools, with a focus on representing concepts as imagery. In addition to the conceptual (function and meaning) characteristics, these patterns also lend themselves to visual representation. As a consequence, explanatory and representational models can be created. In Fig. 1, as noted, metapatterns can be used to analyze a particular phenomenon. However, they can be used as design tools, such as in the design of a classroom community that accounts for both the physical and social dimensions of such a community. The physical layout can be conceived as a metaphoric sphere (containment of the community), even though it is box shaped, with various centers (attractors for various activities), clustering (another potential metapattern) of seating to optimize relationships (binaries and greater), flow pathways (arrows) for moving between different activities, and so forth. The social dimension may be conceived of as a holarchy (concentric spheres) of layers of participation, where the teacher is mentor and primarily occupies the center layer. Students move toward the center as they develop as participants in the learning, inquiry, and/or knowledge producing community.

Thus far the discussion of metapatterns has focused on their use as tools for the study of basic principles of form and function, for analysis of complex phenomena, and for design. Many of these uses are suitable for students in communities of learning, discourse, and engagement. The key point involves a promotion of pattern thinking (Bloom and Volk 2007; Coward 1990). The viewpoint of pattern thinking includes: (1) the embedded and emergent patterns in phenomena; (2) the functions and meanings of patterns; (3) the similarities and differences among patterns across scales; (4) the adaptive value of patterns in evolutionary systems, from biology to culture; (5) the roles of

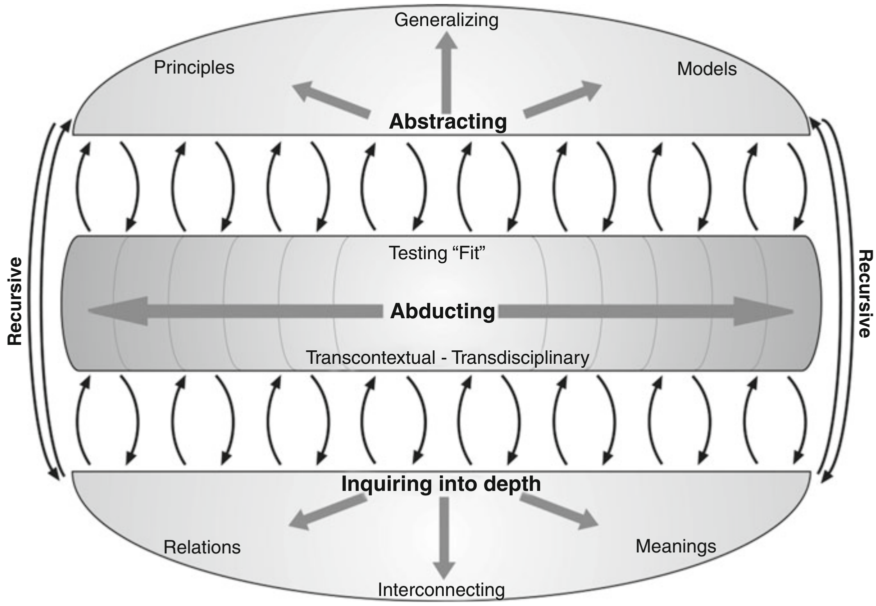


Metapatterns for Research into Complex Systems of Learning. Fig. 1 Example metapatterns-based model of a student argument

parts as individual and interacting components within the complex wholes of systems; and, ultimately, (6) the structure of knowledge and methods of obtaining knowledge across contexts (or subject matter disciplines).

Based on these characteristics of pattern thinking and a metapatterns viewpoint, a research model for complex systems of learning is comprised of three basic components: (1) depth, (2) abstraction, and (3) extent or abduction (Bloom and Volk 2007). The fundamental approach in utilizing this model is one of recursion (Fig. 2). One may begin by inquiring "downward" into depth, while examining the meanings and relationships among parts of systems and various patterns in learning, thinking, discourse, and learning communities. As we engage in this process, we begin to formulate explanatory principles, generalizations, and models "upward" through what is called abstraction in this model. Finally, at the same time, we can explore "horizontally" in an abductive manner to build bridges to related patterns across other contexts and different scales. In this abductive dimension, the patterns involved in bridging will usually have different contexts, such as learning and thinking in schools, in the trades, in corporate settings, across cultures, and so forth. At the same time, this expanding of extent by the abductive use of metapatterns can be applied to testing the "fit" of a new knowledge claim across levels, such as how and what we find with one student fits other students in the class all the way up to people in general.

This model of depth, abstraction, and extent (or abduction) can use metapatterns or any other pattern-concept that from practice can be applied across contexts. The benefits of this model include the potential for increasing rigor in qualitative research. In particular, the abductive use of metapatterns provides a means for determining the limits for claims about various patterns of phenomena, while also providing justifications for such claims. Such a process also provides for a means to formalize scalable explanations,



Metapatterns for Research into Complex Systems of Learning. Fig. 2 A model of complex learning and pattern thinking

where the complete explanation in all detail is applicable to the phenomenon originally investigated, but where degrees of abstraction fit across different scales or contexts.

This model also can be used as a model for learning. As applied to classroom instruction, children can inquire into depth, formulate abstract explanatory principles, and develop transcontextual and transdisciplinary understandings of fundamental patterns and concepts through abductive processes.

Important Scientific Research and Open Questions

- To what extent can this model be utilized across paradigms of research?
- How can degrees of rigor be developed for the application of this model?
- Do researchers find this model more useful and fruitful than some others for the investigation of various phenomena, and if so, which others?

Cross-References

► Abductive Learning
► Abductive Reasoning
► Abstraction in Mathematics Learning
► Complex Learning
► Constructivist Learning
► Critical Thinking and Learning
► Cross-Disciplinary Learning
► Cybernetic Principles of Learning
► Deuterolearning
► Ecology of Learning
► Inquiry Learning
► System Dynamics and Model-Based Learning
► Transfer of Learning
► Transformational Learning

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Metaphor

► Intention Pumps and Augmentation of Learning
► Stories in Psychotherapy

Metaphor Modeling

► Metaphor Therapy

Metaphor Therapy

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Synonyms

Metaphor modeling; Myth; Symbolic therapy; Imagery therapy

Definition

Metaphor is a phrase of speech or image or something that stands for something else. It has two meanings: a concrete direct one and a latent symbolic meaning that represents something else. Metaphor can be verbal, such as biblical parables, myths, legends, and fairy tales, or nonverbal such as art work, music, or object. It is short and vivid but the latent meaning is rich and polymorphic. For instance, the metaphor "*he doesn't bend*" in tough situations may mean: he is stubborn, rigid, a fighter, responsible, proud, or assertive.

The term "metaphor" comes from the Greek and means "*transfer*" or "*to bring beyond*." It meant to express something that is "*beyond*" an immediate concrete or logical understanding and produces new openings on the imaginative and emotional dimension in the person's inner world. Metaphor that is used by the client indicates how he or she communicates with, and represents his or her inner state. Metaphor therapy is an intervention that helps the client to alter the metaphor in order to alter his or her psychological state and behavior. Once the metaphor is changed the client's experience and attitude toward the problem is changed too and he or she becomes capable of considering new ways of coping.

Theoretical Background

Language is a central issue in human learning. Through the stages of development children learn words and concepts to name objects, phenomena, and experiences. Influenced by their culture, children learn to indicate their experiences symbolically and creatively through metaphors. In his seminal book *Interpretation of Dreams*, Sigmund Freud explained how our inner unconscious mind is brought to the dream content through metaphors and symbols. For him interpreting the dream helps us reveal the unconscious and understand the repressed drives and wishes of the patient. Alfred Adler added that the dream work is an attempt to process and solve an unconscious problem in a metaphoric and symbolic language. The use of metaphors in our daily life is similar to the dream because it communicates our inner world to consciousness or to others. It is a sort of dream state while enabling communication with the therapist.

Burns (2001, 2005) considered metaphors as a form of language, a means of communication that is expressive, creative, perhaps challenging, and powerful. As therapy is a language-based process of healing, heavily reliant on the effectiveness of communication between client and therapist, metaphors may best bring the client's inner world to communication and facilitate the process of change. For Burns, metaphor therapy is interactive, attracts attention, nurtures imagination, bypasses resistance, and encourages search process, considering outcomes, decision making, and problem solving.

Kopp (1995) considered the individual metaphors to be analogous to cultural myths where the second are the narrations by which a society is unified while the personal myths are the guiding fictions that unify an individual's personality. In both cases it is a subjective way to construct reality.

The way metaphors are used in therapy varies. Working with dreams as metaphors, Freud allowed himself to interpret the symbols and metaphors and even imposed his interpretation on the client's consciousness.

Unlike Freud and Jung who were interested in interpreting the dream, most metaphor therapists

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focus on mobilizing the metaphoric process toward a metaphoric solution. Milton Erickson was interested in offering a healing process through metaphors. In his work he offered suggestions and brought up metaphors and complex stories to create ambiguity and indirection to help the client develop his or her own unique response (Erickson and Rossi 1979). When a metaphor was mentioned by the client, he worked within the metaphor by parables, interpersonal action, and directives to bring about change. Sometimes he allowed himself to be authoritarian and described his attitude in a metaphoric language: "There are times when the patient comes to you because he wants you to take responsibility, and there are times when you should take on such a responsibility, so you need to be aware of authoritarian techniques and be willing to use them. . . . There are some patients who cannot understand unless you take a figurative baseball bat and hit them over the head with it, and in this case you ought to do it. But I think you have the privilege of whether the bat shall be of soft wood or of hard wood." (Haley 1993, p. 16). In one of the Ericksonian metaphor interventions with a client who suffered from depression since his father's death, the client described his depression as "a heavy stone-like on his chest"; Jeffrey Zeige suggested to him "that he could take something from his yard, perhaps a stone, to the cemetery with him. He could hold the stone against his chest and then place it on the grave site" (pp. 163–164). This metaphoric solution came out of Zeige's understanding of the client's metaphor.

Still other models of metaphor therapies avoid active suggestions, rather they facilitate processing the metaphor to find a solution. Kopp suggested listening to the client language to identify metaphors embedded in his or her language. Once a metaphor is expressed to describe the problem, Kopp suggested three steps of metaphor therapy. In the first step, the client is asked to visualize and describe the metaphor and how it feels. Then he or she is encouraged to be creative and describe the change (solution) he or she wishes to occur in the metaphor. In the last stage, the client is encouraged to learn from the metaphoric changes some practical and applicable actions in his or her life.

In addition to responding to client-generated metaphors, Kopp may encourage the therapist to introduce his or her own metaphors, a process that Kopp described as "listening with the third eye." The therapist, in this process, attends to his or her own internal images and then describes the inner metaphoric image to the client. The therapist might say, "When you were talking about . . . just now, I got an image of. . .]." Such phrasing is permissive, leaving the client free to reject the image and to replace it with one of the client's own.

David Grove emphasized that this process should come from the client while the therapist communicates with the client in the client's language in order to help him or her in watching the metaphor develop of its own accord to the point where the problem resolves. In Grove's work the whole of the client's inner world is explored, including the position of the symbols in relation to the client. Sounds, signals, and the body language of the client are taken into account. After the metaphor is clear and vivid, the therapist asks "What would you like to have happen?", shifting the focus toward a positive outcome (Grove and Panzer 1989).

Grove insisted in using a *Clean Language* that is based solely on the client metaphor avoiding any contamination with the therapist's associations and inner world. When a client says "I feel stuck in my life" the therapist will not ask "how you will find your way out" because this question suggests finding a way out. In clean language the therapist may ask in a neutral tone of voice "*And that 'stuck' is 'stuck' like what?*" The idea is to not contaminate the client's metaphors with the therapist's preconceived ideas or suggestions. The therapist tries to get the client to develop and expand on their statements without influencing the client's mental processing in any way. In order to encourage the client to communicate through metaphors Grove asks the client to give shape and color to the problem.

Metaphors were used for several functions and purposes. In their review of the literature Lyddon et al. (2001) found that metaphors were used in (a) building relationships with clients, (b) accessing and symbolizing client emotions, (c) uncovering and challenging underlying client assumptions, (d) working with client resistance, and (e) introducing new frames of reference.

In addition to employing metaphors in psychosocial problems, it is important to know that it was employed in medical problems too. Bresler (1984) for instance, employed metaphors in a technique that he called "mind-controlled analgesia" to alleviate pain. In this technique, the patient is asked to draw three pictures: one that symbolizes pain at its worst, a second that symbolizes pain at its best, and a third that symbolizes an intensely pleasurable experience. After inducing a state of relaxation, the patient is asked to vividly experience the first picture (the pain at its worst), then this experience is transformed into the second picture (that symbolized the pain at its best) and finally, the patient is encouraged to experience the pleasurable image. Patients are given prerecorded cassette tapes containing directives to practice several times a day. Simonton et al. (1978) used imagery to control the immune system activity. They trained cancer patients to draw and imagine their white blood cells activated against the cancer cells. They reported that this imaginative activity alleviated the development of the disease. Today imagery techniques are widely used in a variety of medical problems.

Important Scientific Research and Open Questions

Metaphors have been used by Sigmund Freud, Carl Jung, Milton Erickson, Carl Rogers, and many others. It was used in a variety of interventions: family therapy, Jungian therapy, NLP, hypnosis, counseling, psychotherapy, coaching, and supervision. How does it work? Bateson (1979) thought that metaphors, rather than logic, are the main characteristic of the mental health organization and represent the logic upon which the biological world was built. Ricoeur (1986) stipulated that metaphors work as an intermediary process or bridge between the logic language of the rational thinking and the analogical language of the emotions, imagination, and affections, which allow an access to emotions and feelings in the therapeutic relationship. For Campbell (1988) it allows new knowledge and ideas to be conveyed using frames of reference that are familiar to the learner; thus, metaphors give familiarity to the unfamiliar, and making new information seems less overwhelming and more easily understood.

Psychoanalysts believe that metaphors reach the affective unconscious field avoiding the defense mechanisms and elude the resistance. All this happens without making the unconscious explicit but still opens spaces for a more free and creative translation by the client. Kopp (1998) made an analogy between metaphors and Adlerian early recollection. He indicated two similarities between the two: both are images from childhood and both are not literally true.

Dwairy (1997) has proposed a biopsychosocial model that explains how metaphors influence the mind, body, and social life. This model assumes two-way relationships between dreams, imaginations, and metaphors on the one hand and the psychological, biological, and social experiences on the other, indicating that metaphoric solutions are not imaginative ones, rather they are very real and influential solutions. Based on the ideas of Freud, Rogers, and cognitive therapists, this model assumes two-way relationship between metaphors on the one hand and the psychological conscious and unconscious experiences on the other. The language that communicates between the two realms is symbols. The second two-way relationship is based on neuro-endocrine sciences that explain how neurotransmitters, hormones, and peptides communicate between images and body. The third relationship is between metaphors and the social and cultural experiences. This relationship is built upon myths, proverbs, and cultural idioms (Fig. 1). Based on this model once the client reaches a metaphoric solution for his problem, these new images generate new real psychological, physiological, and social changes. Dwairy (2003) was pioneer in using the client's physical environment as metaphors in order to promote change. For him, objects in the clients' physical environment are not inanimate, rather they carry personal meanings, memories, and emotions. Once the client addresses in therapy significant objects from his home, he or she addresses significant personal experience or memory. Changes in the position of the object, such as retrieving it from the drawer and placing it in the sitting room, may be associated with changes in the personal and psychological client's life.

One of the major differences in the application of metaphor therapy is related to the therapist's role in the metaphor generation and processing. Milton Erickson, for instance, suggested and sometimes imposed the metaphor in the client's mind. On the other hand, Grove, for instance, insisted on using a *clean language* that prevents contamination of the client's own experience by the therapist's own assumptions and biases.

Based on the idea that metaphor therapy influences the mind and the body without revealing the unconscious content, it is recommended with clients who possess collective values. This is because therapy that reveals unconscious content that is typically forbidden among such clients, in fact, generates a tough

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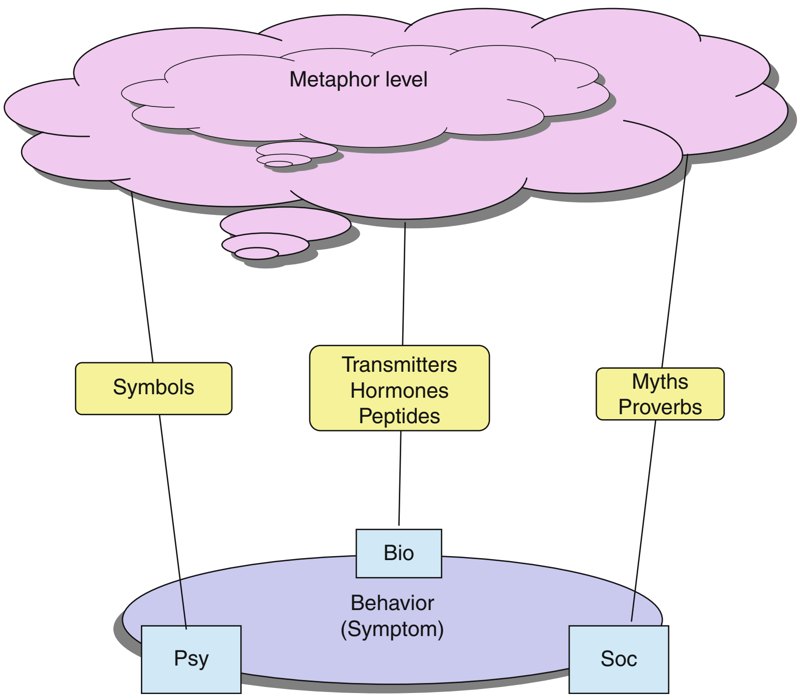

Metaphor Therapy. Fig. 1 Dwairy's biopsychosocial model of metaphor therapy

confrontation between the client and his or her family or tribe (Dwairy 2006). Therefore, metaphor therapy influences the deep unconscious domain without evoking such confrontation.

Metaphor therapy is embedded in many therapies such as psychoanalysis, art therapy, play therapy, biblio-therapy, music therapy, and many others. As the clinical work and publication on metaphor therapy is huge, the empirical research on metaphor therapy is rare.

Much research has shown that metaphor therapy can be influential in conjunction with other therapies. For instance, Naziry et al. showed that cognitive therapy integrated with metaphor therapy is more influential on depressive patients than cognitive therapy that is solely rational. These results are consistent with previous research that showed that usage of metaphor in psychotherapy improves the efficacy of treatment (i.e., Angus and Rennie 1988; Angus and Korman 2002; Levitt et al. 2000; Martin et al. 1992; Mcmullen 1989; Mcmullen 1996; McMullen and Conway 1996).

Guiffrida et al. (2007) reviewed the empirical research made on the effectiveness of the use of metaphors in supervision and found no proofed validation for such effect, but only anecdotes that support this assertion. Based on the research found, metaphor therapy typically is effective when it is applied within a wider psychotherapeutic approach.

Milioni (2007) conducted a qualitative research based on interviews with therapists and clients and found that metaphors may serve the power relationship between the therapist and the client. It is used as a silencing device in the hands of therapists and to resist the client's worldview and impose another that is favored by the therapist. Such use results in alienating the client since the meaning of the metaphor is not arrived collaboratively or after checking out the meaning with the client. In her conclusion Milioni argues that it is not metaphor as a technique that is problematic in itself, rather it is the instrumentalist view of metaphor that makes it oppressive and controlling.

A comparative research is needed to study the impact of such therapies with different people who have different problems. Still another question needs to be studied: How metaphor therapy may work with clients from cultures whose language is a metaphoric one, such as the Arabic language, as compared to cultures whose language is more direct.

Cross-References

- ► Analogy Therapy
- ► Experiential/Significant Learning
- ► Metacognitive Processes in Change and Therapy
- ► Psychoanalytic Theory of Learning
- ► Stories in Psychotherapy

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Metaphorical Thinking

► Analogical Reasoning

Metareasoning

► Introspective Learning and Reasoning

Metatheories of Learning

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Synonyms

Holistic learning theory; Integrated learning theory; Unified learning theory; Whole-part-whole learning

Definition

At the basic level *meta* means going higher or transcending, *theory* means a formulation of

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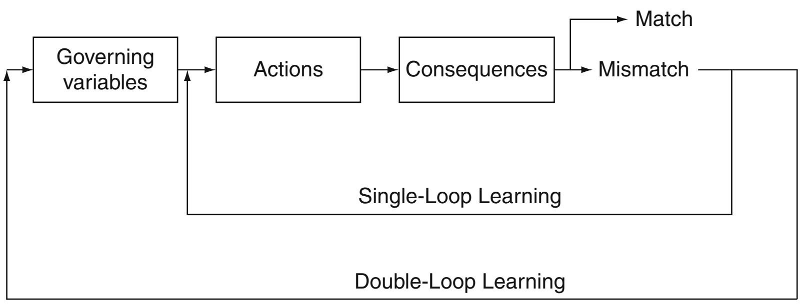


Metatheories of Learning. Fig. 1 Single-loop and double-loop learning (Argyris 2004, p. 68)

relationships or underlying principles of an observed phenomenon, and *learning* means the acquiring of knowledge or expertise. Thus, metatheories of learning are higher order or transcending theories of how knowledge and expertise are acquired.

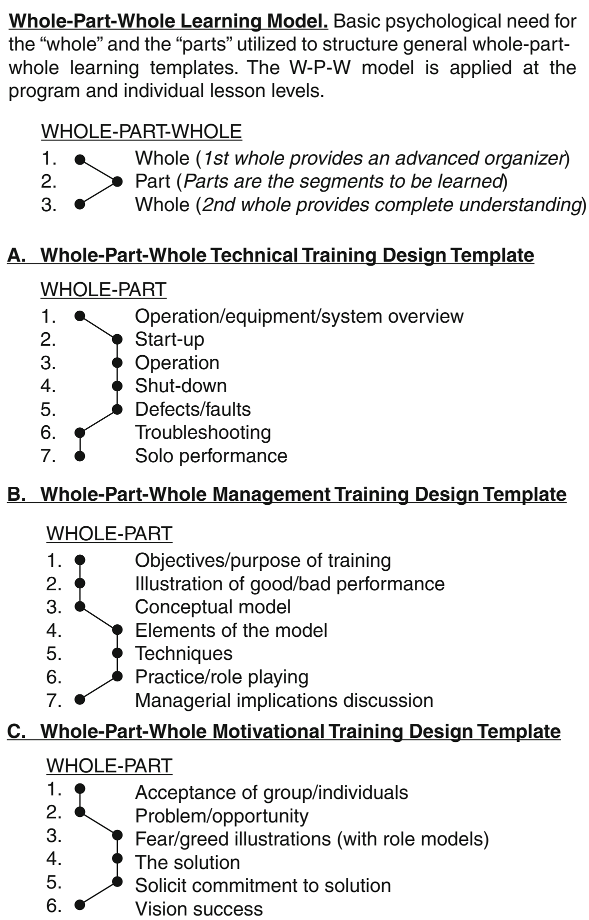
Theoretical Background

While the idea of metatheories of learning is old, this realm remains largely undeveloped. For example, discredited faculty psychology suggested types of people and their corresponding ways of acquiring knowledge and expertise. Because of the complexity of human beings, the inclination among learning theorists and researchers has been toward focused or incremental investigation. The result has been numerous highly refined learning theories with limited application.

An interesting observation is the perspective among most of those pursuing metatheories of learning. Most of the work has come from scholars who have been close to practical learning issues versus the laboratory perspective. Some examples include Gagné's (1962) "Military Training and Principles of Learning." After years of working on military training issues, Gagné critiqued the field of learning psychology as spending too much time studying what was going on inside the learner instead of studying what was to be learned. Thus, his learning principles shifted from analyzing the learner to analyzing what was to be learned.

Argyris's (2004) learning theory is another example of looking at learning within the context of organizations. His focus on actions, errors, along with single-loop and double-loop learning creates an overarching view of the learning process (see Fig. 1).

The *Whole-Part-Whole* learning model is an integrated learning theory combining behavioral (the parts)



Metatheories of Learning. Fig. 2 Whole-part-whole learning model (Swanson and Holton 2009, pp. 240–241)

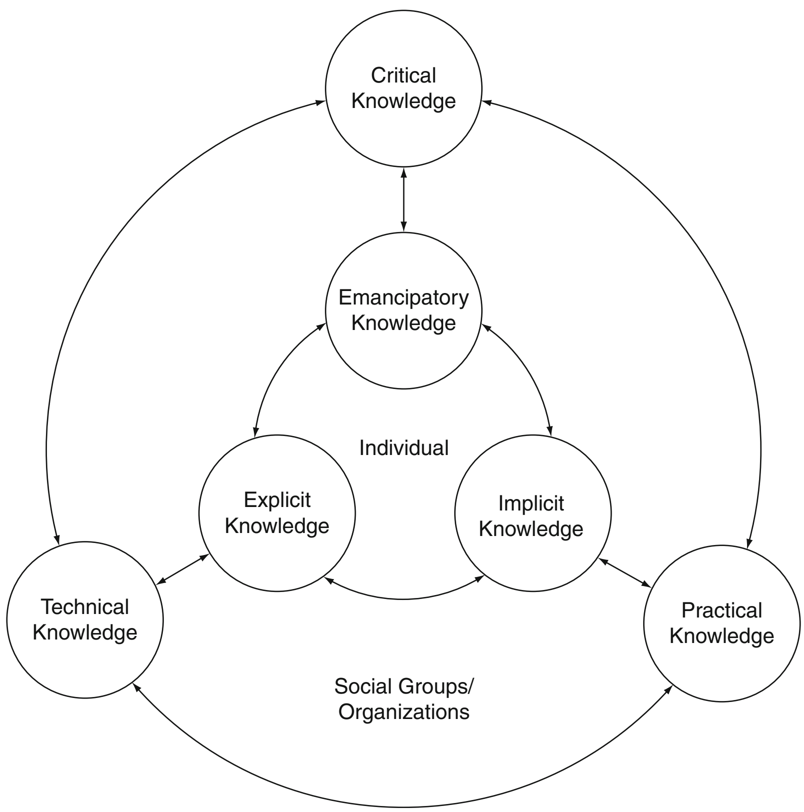
and gestalt (the whole) psychologies to meet the requirements of gaining knowledge and expertise within contexts of life and work (Swanson and Holton 2009, pp. 240–241). Specifically, this functional integration of learning theory bridged learning theory and design and utilizes learning design templates for different categories of learning (see Fig. 2).

Going even further, Davis and Davis (1998) identified seven categories of learning required of adults working in organizations. These categories serve as a means of accessing the milieu of learning theory and research appropriate to acquiring that particular type of knowledge and expertise. Based on extensive field research of the learning needs in organizations, they created seven specific learning strategies organized around the seven general areas of expertise required to function in contemporary organizations. Their approach is to start from the identified realm of expertise required, then to proceed to the selection of an appropriate learning strategy, and to provide complete details related to the conduct of the strategy based on learning research. The seven strategies proposed by Davis and Davis include:

- The Behavioral Strategy: *Skill Development and Coaching*
- The Cognitive Strategy: *Presentations and Explanations*
- The Inquiry Strategy: *Critical, Creative, and Dialogical Thinking*
- The Mental Models Strategy: *Problem Solving and Decision Making*
- The Group Dynamics Strategy: *Human Relations and Teamwork*
- The Virtual Reality Strategy: *Role Play, Dramatic Scenarios, and Simulation*
- The Holistic Strategy: *Mentoring and Counseling*

These examples again illustrate the pressure that practice plays on ensuring learning success and the willingness of scholars to entertain meta-learning theories to meeting learning demands.

Yang's (2003) "Holistic Learning Theory" is another important contribution for working toward



Metatheories of Learning. Fig. 3 Holistic theory of knowledge and learning: dynamic relationships between individual, organizational, and social/cultural contexts (Yang 2003)

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Aspect	*Behaviorist*	*Cognitivist (Gestalt)*	*Humanist*	*Social Learning*	*Constructivist*	*Holistic*
Learning theorists	Thorndike, Pavlov, Watson, Guthrie, Hull, Tolman, Skinner	Koffka, Kohler, Lewin, Piaget, Ausubel, Bruner, Tolman, Gagne	Maslow, Rogers, Knowles	Bandura, Rotter	Candy, Dewey, Lave, Piaget, Rogoff, von Glaserfeld, Vygotsky	Yang, Jarvis & Parker
View of the learing process	Change in bahavior	Internal mental process (including insight, information processing memory, perception)	A personal act to fulfill potential	Interaction with and observation of others in a social context	Construction of meaning from experience	Involves facets of explicit, implicit, and emancipatory knowledge
Locus of learning	Stimuli in the environment	Internal cognitive structuring	Affective and cognitive needs	Interaction of person, bahavior and environment	Internal construction of reality by individual	Occurs as a result of interactions with and between knowledge facets
Purpose of education	Produce behavioral change in desired direction	Develop capacity and skills to learn better	Become self-actualized, autonomous	Model new roles and behavior	Construct knowledge	Systematization, participation, and transformation
Teacher's role	Arranges environment to elicit desired response	Structures content of learning activity	Facilitates development of whole person	Models and guides new roles and behavior	Facilitates and negotiates meaning with learner	Facilitator
Manifestation in adult learning	■ Behavioral objectives ■ Competency-based education ■ Skill development ■ Skill development	■ Cognitive development ■ Intelligence, learning, and memory as function of age ■ Learning how to learn	■ Andragogy ■ Self-directed learning	■ Socialization ■ Social roles ■ Mentoring ■ Locus of control	■ Experiential learning ■ Self-directed learning ■ Perspective transformation ■ Reflective practice	■ Holistic and dialectical perspective ■ Dynamic

Metatheories of Learning. Fig. 4 Six orientations to learning (Source: Swanson and Holton 2009, p. 195)

a higher or transcending learning theory (see Fig. 3). His theory embraces three indivisible facets – implicit, explicit, and emancipatory knowledge. Each facet has three layers – foundation, manifestation, and orientation. The value of the holistic theory, as a metatheory of learning, is in making connections between seemingly disparate streams of philosophy and research related to knowledge and learning.

Important Scientific Research and Open Questions

Attempts at metatheories of learning to this point are relatively immature compared to many recognized elemental learning theories. The fundamental challenge for meta-learning theorists is to fuse the behaviorist, cognitivist, humanist, social, constructiveness, and holistic orientations to learning theory displayed in Fig. 4 (Swanson and Holton 2009, p. 195). To achieve this, meta-learning theories require continued conceptualization and validation.

Existing attempts at metatheories of learning are attractive to those overseeing practical learning situations and they do have a reasonable record of utility. Thus, applied research in practice may be the most appropriate way of advancing the understanding and effectiveness of meta-learning theory models and the promise of reaching verified theory status. Such an approach would logically require a partnership of engaged scholarship between researchers and practitioners to get at a deeper and higher order understanding of metatheories of learning.

Cross-References

► Approaches to Learning and Studying
► Blended Learning
► Conditions of Learning
► Double-loop Learning
► Expertise
► Formal Learning Theory
► Learning in Practice
► Learning Strategies
► Meaningful Verbal Learning
► Organizational Learning

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Meta-Thinking

► Metacognition and Learning

Method

► Cue Summation and Learning

Methodologies of Learning Research Through the Internet

► Web-Based Experiment Control for Research on Human Learning

Methodologies of Research on Learning (Overview Article)

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Synonyms

Paradigms of learning research; Scientific method

Definition

► *"Good methodology is essential to good science"* (Simon and Kaplan 1989, p. 20).

The term "methodology" refers to the theoretical analysis of research methods in a discipline that are generally considered appropriate for the inquiry of relevant or important issues. It may refer to a set of methods or procedures or to the rationale which underlies a particular study relative to the applied ► scientific method, which basically consists of the collection of data through observation and/or experimentation, and the formulation and testing of theoretically sound hypotheses. The choice of a particular methodology is often determined by a ► paradigm, i.e., the goals and interests which scientists strive for.

Theoretical Background

Every discipline that maintains a theoretically sound interpretation of its fundamental statements depends on both the applied terminology and methodology. However, this is to a large extent dependent on the paradigm a scientist is striving for. In his seminal textbook *The Structure of Scientific Revolutions*, Kuhn (1970) defines a scientific paradigm as: (1) *What* is to be observed and scrutinized. (2) The kind of *questions* that are supposed to be asked and probed for answers in relation to this subject. (3) *How* these questions are to be put. (4) *How* the results of scientific investigations should be interpreted. The paradigm, in Kuhn's view, is not simply the current theory, but the entire worldview in which it exists, and all of the implications which come with it.

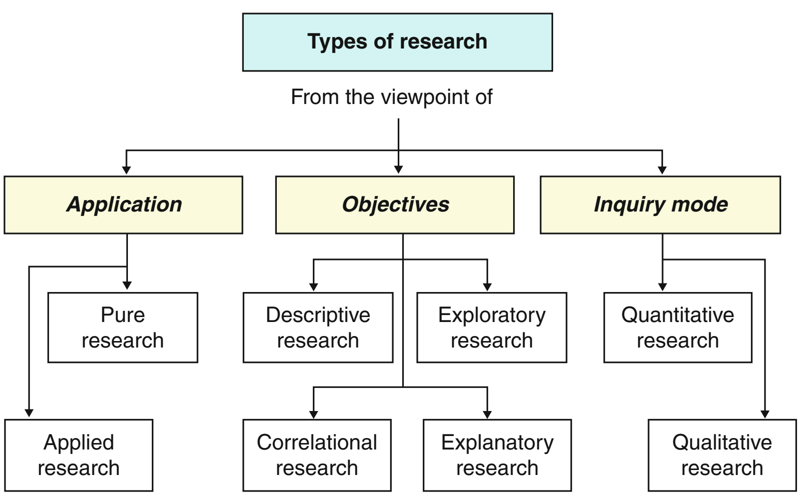
Since the learning process itself is not visible, talking about learning and related phenomena was a standard procedure for more than 2,000 years. Actually, introspection was the most prominent method for gaining "insight" in learning, forgetting, and remembering. An alternative paradigm and corresponding methodologies emerged at the end of the nineteenth century when Ebbinghaus and others applied the paradigm of experimental research on learning and forgetting. Within the realm of this paradigm, learning can only be "deduced" from observable changes in behavior, the result of which are referred to as *outcomes of learning*. Accordingly, behaviorist psychologists attempted to limit their studies to the recording of objectively observable and measurable behavior without describing the content of consciousness and cognitive processes. The stimulus–response pattern became the dominant paradigm of this branch of psychology of learning for the twentieth century. On the other hand, Gestalt psychology had at this time already begun to view learning as a process of structuring founded on insight into structural relationships. Gestalt psychologists see *learning through insight* as a process of reorganization in which new structures are integrated into the learner's field of perception. Perceived objects change their function and are compared with one another until the moment of insight, when the complete organization of the situational field becomes clear to the learner. This approach was extended by Lewin's field theory, in which learning is first and foremost understood as a change in cognitive structures (or in knowledge).

These paradigms and related methodologies characterize the area of learning research until today. Actually, every discipline uses alternative research methods and procedures in order to increase understanding of the phenomena of interest and to advance the knowledge base. These methods and procedures are usually developed and discussed by research methodologists in order to meet high standards of the scientific method. In general, research can be classified into three major categories: (1) core and scope of *application*, (2) guiding *objectives* in undertaking research, and (3) the particular *inquiry mode* employed in a research study (cf. Goddard and Melville 2001; Kumar 2005).

Based on these epistemic categories, we can distinguish particular types of research on learning (see Fig. 1).

Every research project can be classified from the perspectives of application, objectives, and inquiry mode: From the perspective of application, research on learning may be classified as pure or applied research; from the perspective of objectives, a research study can be descriptive, correlational, explanatory, or exploratory; and finally, from the perspective of inquiry mode, research on learning can be qualitative or quantitative.

From the perspective of application, *pure research* (also termed *basic research* or fundamental research) advances fundamental knowledge about learning; it aims at testing hypotheses derived from theories on learning. Basic research is usually experimental by nature and aims at collecting data and facts for supporting theoretical assumptions without any particular application in view. There are different types of methods which constitute the body of methodology of pure/basic research: In the related literature, usually *laboratory experiments* are listed on the top of basic research. They are conducted in strictly controlled settings which allow to vary systematically particular (so-called experimental) variables of interest and assess their effects on learning. Most characteristically, participants are randomly assigned to experimental and control conditions and the relevant variables are carefully assessed (often by means of standardized test procedures). Whereas laboratory experiments are conducted in artificial settings, *field experiments* are conducted in more naturalistic settings. However, field experiments, like lab experiments, generally randomize the sampling of participants and their assignment into treatment and control groups and compare outcomes between these groups. Actually, randomization of participants to treatments has long been considered a powerful method of control, so much so that this is the distinguishing characteristic between true experimental and other types of research (Campbell and Stanley 1965). However, randomization is typically unavailable in field settings because the researcher is not able to manipulate treatment conditions at the level of the individual participant. In addition, it is difficult to control the relevant variables in a field experiment, while we can rigorously control these variables in a laboratory experiment. Within the realm of field research, it is also possible to conduct *cross-sectional*



Methodologies of Research on Learning (Overview Article). Fig. 1 Types of research (Kumar 2005, p. 9) *studies* which survey a large and representative sample of participants at one point in time. A good example for such a cross-sectional field research is ► PISA. Finally, field experiments can also be conducted as *longitudinal studies* which evidently offer the best way to study long-term effects of exposure to learning settings. Longitudinal studies survey the same group of individuals at several different times over long periods in order to detect long-time progressions of cumulative learning. This method of field experimentation is designed to detect causal relationships and statistically control for environmental, family, and personal characteristics that might otherwise account for learning progression. From here to ► multilayer investigations, it is only a small step. Pure or basic research is not only concerned with the conduction of lab and/or field experiments but rather also with the development, examination, verification, and refinement of research methods, procedures, techniques, and tools that form the body of the basic research methodology. In contrast to basic research, *applied research* deals with practical problems of learning and related phenomena. Specific techniques, procedures, and methods form a research methodology oriented to practical issues. An extreme position of applied research is *action research* as a form of self-reflective inquiry aiming at the improvement of behaviors in social situations.

From the perspective of objectives in undertaking research on learning, a research study can be descriptive, prescriptive, correlational, explanatory, or exploratory. Simply said, *descriptive research* deals with everything that can be counted. Therefore, it is also named statistical research which aims at describing characteristics about a phenomenon being studied by means of descriptive statistics. However, descriptive research cannot be used to examine causal relationships between variables. This holds also true with regard to *correlational research* which aims at the determination of a relationship or interdependence between two or more features of subjects of interest, such as the relationship between achievement and intelligence. In general, a correlational study is a quantitative method of research in which two or more quantitative variables from the same group of subjects may covariate. Theoretically, any two quantitative variables can be correlated as long as the scores on these variables refer to the same subjects; when there is little reason to assume a relationship between the variables, it is probably a waste of time to collect data. Correlational research is clearly not suitable for discovering causal relationships between variables but it can be the starting point for *predictive research* aiming at the probabilistic prediction of criteria of interest by utilizing information from variables that are considered as predictors. As Pedhazur and Pedhazur Schmelkin (1991) have pointed out, in a predictive study the variables of interest may be selected, retained, or dropped solely on the basis of practical considerations. In contrast, *explanatory research* is aimed at testing of hypotheses derived from a theory which explains a phenomenon of interest. The defining characteristic of explanatory research is the random assignment of participants to the particular conditions of an experiment. In consequence, randomization of participants to treatment conditions has long been considered as the most powerful method of experimental control, so much so that it became the distinguishing characteristic between experimental and other types of research (Shadish et al. 2002). Explanatory research attempts to clarify *why and how* there is a relationship between two features of a situation or phenomenon. Accordingly, explanatory research is often considered as a best example of causal research. However, causal inferences have to be based on sound theories and hypotheses. That means that theoretical arguments have to specify the particular regularities or even mechanisms for how a particular event or treatment (i.e., the cause) consistently produces an effect in time (discussed in terms of "if and only if x, then y"). To progress from here to probabilistic predictions is only a small step. Indeed, explanatory and predictive research is not mutually exclusive. Nevertheless, the distinction between them is imperative, as it has far-reaching implications for data collection, choice and application of analytic procedures, and interpretation of results.

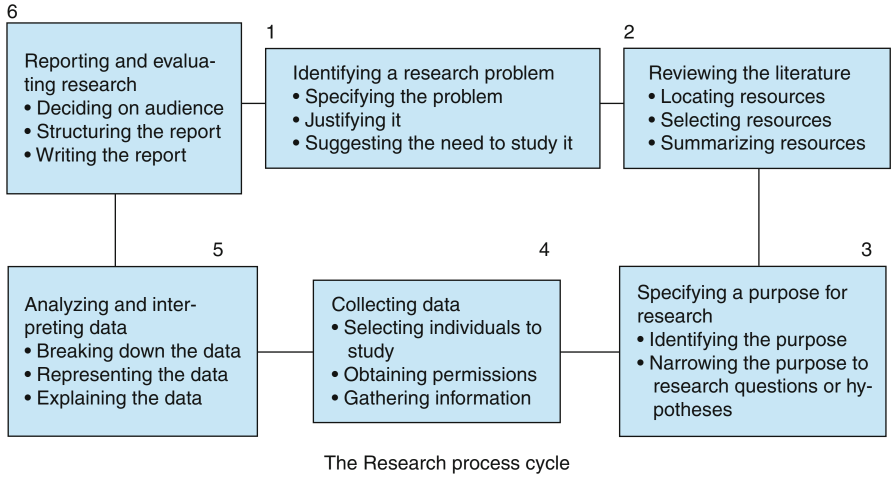
The last type of research to be mentioned here is called *exploratory research* and is undertaken with the goal either to explore an area of interest or to examine the feasibility of particular research. Accordingly, we speak about a pilot study or feasibility study that provides insights into and comprehension of an issue or situation. Exploratory research may help to find a suitable research design, data collection method, or selection of subjects. However, conclusions from exploratory research should be considered with caution because they are certainly not generalizable to the population at large. Although the process is not linear in practice, exploratory research often precedes descriptive research which generally goes before explanatory research.

From the perspective of the *inquiry mode* employed in research on learning, two broad approaches compete against each other since a long time. They are usually classified as *quantitative* versus *qualitative research.* Alternatively, Kumar (2005) speaks about the structured (= quantitative) versus unstructured (= qualitative) approach of research. In terms of this author, the structured approach can be characterized by a predetermination of everything that forms the research process – objectives, design, sampling, data collection, and analysis. The unstructured approach, by contrast, allows flexibility in all these aspects of the research process. An analysis of the literature on research methodologies shows that quantitative and qualitative research are often considered as mutually exclusive antipodes according to which we can do either quantitative (structured) or qualitative (unstructured) research but not concertedly. This contrastive position neglects the possibility of mixed-methods research as well as the fact that the choice of a structured or unstructured research approach, and in consequence of a quantitative or qualitative mode of inquiry, should depend on the mission and objectives of the inquiry (e.g., exploration, confirmation, quantification, and hypothesis testing) and the intended use of the results (e.g., for hypothesis testing or improvement of learning practices). In qualitative research studies, it is not the intention to generalize to a population at large but to develop an in-depth exploration of a phenomenon of interest (Creswell 1998).

Important Scientific Research and Open Questions

In general, most methodologists and researchers agree on the steps in undertaking research – independently on the particular inquiry mode or the objectives. Kumar (2005), for instance, describes the research process in form of an eight-step model: (1) Formulating a research problem, (2) conceptualizing a research design, (3) constructing an instrument for data collection, (4) selecting a sample, (5) writing a research proposal, (6) collecting data, (7) processing data, and (8) writing a research report. In a similar vein, Creswell (2005) describes the research process as a cycle of six steps (see Fig. 2).

In addition, most methodologists agree on the classification of the aforementioned types of research from the different perspectives. In consequence, it is not difficult to classify and evaluate the existing body of research on learning in accordance with the perspectives of application, objectives, and inquiry mode. Actually, it is quite easy to find an abundance of research studies in the field of learning that can be classified as pure or basic as well as applied, although meanwhile more and more studies are applied in nature and increasingly very little research in the field of learning is pure in nature. Furthermore, very few people do research in research methodology per se. In



Methodologies of Research on Learning (Overview Article). Fig. 2 The research process cycle (Creswell 2005) consequence, there is no unique methodology for research on learning but only broad and comprehensive guides for undertaking research in the field of social studies in general.

Another critical comment refers to the low complexity of the research designs in studies on learning. Traditionally, the effects of treatments on learning are assessed by a simple comparison between a pretest and posttest and the leading paradigm corresponds with the idea of "looking into the black box." The following procedure is often applied: After an initial training and a so-called learning phase which is experimentally varied, the subjects have to perform specific tasks considered indicative for successful learning. Evidently, the trickiest problem of such studies is to define adequate dependent variables to evaluate the quality of learning.

Another significant problem has been highlighted from Donald Norman (1981) with these words:

- There has been remarkably little study of learning – real learning, the learning of complex topics, the learning that takes months, even years to accomplish. Elsewhere I have estimated that experts at a task may spend 5,000 hours acquiring their skills: that is not such a long time; it is 2 1/2 years of full-time study, 40 hours a week, 50 weeks a year. Not much time to become a professional tennis player, or computer programmer, or linguist. What goes on during that time? Whatever it is, it is slow, continuous. No magic dose of knowledge in the form of pill or lecture. Just a lot of slow, continual exposure to the topic, probably accompanied by several bouts of restructuring of the underlying mental representations, reconceptualizations of the concepts, plus many hours of accumulation of large quantities of facts [. . .] Very little effort gets spent at studying what it would take to accomplish this, perhaps because there is the implicit realization that the task is harder than it might seem. [. . .] And so the study and understanding of the learning process remains at a miniscule level. Pity (Norman 1981, p. 284).

In contrast to this verdict, there is evidently a lack of longitudinal research on learning in general as well as on cumulative learning in particular. Nevertheless, occasionally we can find some examples for longitudinal research on learning (see, e.g., Halle et al. 2009; Saldana 2003).

A final critical comment concerns the lack of replication studies in the field of learning research. More than 30 years ago, Bronfenbrenner (1978) argued that experimental replications involve the potential to increase successively the confidence in empirical data and their theoretical interpretations due to the evidence that particular results (of treatments or interventions) are not limited to a single case. At the same time, Cook and Campbell (1979) argued that many small experiments with internal validity may contribute more to the external/ecological validity of investigations than big national studies which lack internal validity. Actually, replication studies are essential with any construct of interest in order to provide further depth and understanding. Methodological authorities such as Cook and Campbell (1979) generally regard replication, or what is also referred to as "repeating a study," to be a crucial aspect of the scientific method in general. The right kind of repetition means that a previous result will have its scope extended. It leads to generalizable results, rather than merely to isolated and uncertain findings. In the physical sciences, important findings get repeated hundreds of times, first deliberately and then as a built-in part of subsequent work. But replication in the social sciences and especially in the sciences of learning is rare.

Cross-References

► Action Research
► Design Experiments
► Experimental and Quasi-Experimental Research on Learning
► Field Research
► Mixed Methods Research

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Methodology of Learning Research: Meta-analyses

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Synonyms

Quantitative research synthesis; Quantitative review

Definition

A meta-analysis is a quantitative synthesis of primary empirical studies on a specific research topic. General goals of a meta-analysis are: (1) to give a comprehensive overview of the current state of research in a specific field, (2) to aggregate the findings of multiple empirical studies in order to give a precise estimate of the population effect size, and (3) to test the influence of different substantive and methodological moderator variables on the effect size estimate.

In the context of learning, meta-analyses are typically conducted in order to evaluate the effect of specific interventions or learning methods across different samples and environments (e.g., Vernon and Blake 1993). However, meta-analyses can also be used for other research questions, for instance, in order to contrast and evaluate different theoretical explanations for a specific phenomenon.

Theoretical Background

Strengths and Limitations of Meta-analyses

Meta-analyses offer a broad overview of the research field and can help to identify limitations or even gaps in previous work. In addition, meta-analyses provide an estimate for the population effect size which, due to the much larger sample size, is much more precise than the effect sizes estimated from single-sample studies. This summary effect size indicates, for instance, whether a specific learning method is, on average, effective across multiple samples and contexts. In addition to the summary effect size, meta-analyses also provide information on the variance of effect sizes between different studies. In additional moderator analyses, it is possible to examine which substantive and methodological variables account for this variance. In sum, meta-analyses are powerful tools to synthesize primary empirical research and to draw general conclusions about the effectiveness of interventions or the validity of theories. However, a number of limitations shall not be concealed.

First, the quality of the meta-analytic findings depends heavily on the quality of the primary studies that deliver the data. Poorly designed studies can bias the estimate of the average effect size. The most conservative way to cope with poor study quality is to exclude all studies that do not reach certain minimum standards. However, this approach might lead to a significant exclusion rate of studies and consequently to a loss of statistical power. Alternatively, meta-analysts sometimes code different study characteristics related to the study quality (e.g., selection of participants, randomization) and calculate an index variable indicating the overall quality of this study. This study quality variable can then be included in additional moderator analyses.

A second, related issue concerns the reporting of methods and results in the primary studies. Meta-analysts often find that neither effect sizes nor sufficient descriptive statistics are reported. Also, important information about the sample, procedure, and measures can be missing. In this case, meta-analysts should seek to contact the authors of the primary studies and ask for the missing information.

A final limitation may result from the exclusion of studies. This is particularly problematic if the effect sizes provided by these excluded studies differ systematically from the effect sizes provided by the included studies, for instance because studies with nonsignificant findings often remain unpublished. If these unpublished studies are not detected, the summary effect size may be positively biased. For this reason, meta-analysts should always try to retrieve unpublished data in addition to published studies, for instance by contacting potential authors directly or by sending requests to academic listservs. In addition, the amount of potential bias should be estimated, for instance by plotting the effect sizes against the sample sizes in a funnel plot, or by regressing the effect sizes against the sample size and statistically testing this regression coefficient.

Steps

Meta-analyses are usually performed along a number of sequential steps. It is helpful to document each step in as much detail as possible.

Step 1: Formulation of a Research Objective

It is important to formulate the research objective as precisely as possible. Some decisions made at this point include: (a) What is the overall research question or hypothesis? (b) Which variables or constructs are of interest? How are these variables (typically) measured? (c) What type of studies should be included, what type of studies should be excluded?

Step 2: Literature Search and Study Selection

To develop a coherent strategy for the literature search, the authors must develop a list of appropriate keywords and choose scientific data bases to be searched. After running the literature search, the studies are screened for eligibility according to the inclusion and exclusion criteria defined in Step 1. Eligible studies enter the coding process.

Step 3: Study Coding

Important characteristics of the studies are coded, meaning that, numeric codes are assigned to different characteristics. Coded characteristics typically include features of the publication (e.g., publication year), design characteristics (e.g., existence of a control group in intervention studies), sample characteristics (e.g., proportion of males, mean age), and descriptive statistics (e.g., means, standard deviations, correlations). The codes are entered on a standardized coding sheet that is accompanied by an extensive coding manual. To estimate the reliability of these codings, it is recommended that each study is coded twice and appropriate indicators of interrater agreement are calculated and reported.

Step 4: Calculate Effect Sizes

Although effect sizes are increasingly reported in journal articles today, it might still be necessary to calculate effect sizes based on the reported descriptive data. Various effect sizes for different metrics and purposes have been proposed (e.g., standardized mean difference, odds ratios). Descriptions and formulas for these effect sizes can be found in most standard textbooks on meta-analysis (e.g., Borenstein et al. 2009; Lipsey and Wilson 2001). Formulas for the most commonly used effect sizes are presented in Table 1. The estimated effect sizes may be biased by a variety of factors, for instance, sampling bias and unreliability. For this reason, effect sizes are often corrected for bias. A large number of adjustment formulas for various sources of bias have been proposed (Hedges and Olkin 1985; Hunter and Schmidt 1990).

In addition, it is necessary to calculate the standard error of each effect size. This measure indicates the degree of preciseness of the effect size and depends, among others, on the sample size, with larger samples providing more precise estimates. In some meta-analytic approaches, the effect size is weighted using the inverse variance weight (i.e., the inverse of the squared standard error) to ensure that more precise effect sizes receive more weight in the estimation of the summary effect size. Formulas to calculate the standard error of different effect sizes are presented in Table 1 and can also be found in standard textbooks on meta-analysis.

Step 5: Data Analysis

Two fundamentally different statistical approaches to meta-analyses can be distinguished (e.g., Borenstein et al. 2009): In fixed-effects models, it is assumed that all variance between the effect sizes of different studies

Methodology of Learning Research: Meta-analyses. Table 1 Formulas for common effect sizes and the respective standard errors

Type of effect size	Description	Formula for effect size	Standard error
Bias-corrected standardized mean difference	Mean-level difference between two independent samples, e.g., intervention vs. control group	$ES'_{sm} = \frac{\bar{X}_{G_1} - \bar{X}_{G_2}}{s_{pooled}} \cdot \left(1 - \frac{3}{4 \cdot N - 9}\right)$	$SE_{sm} = \sqrt{\frac{n_{G_1} + n_{G_2}}{n_{G_1} \cdot n_{G_2}} + \frac{(ES'_{sm})^2}{2 \cdot (n_{G_1} + n_{G_2})}}$
Standardized mean gain	Mean-level change between two time points, e.g., from pretest to posttest	$ES_{sg} = \frac{\bar{X}_{T_2} - \bar{X}_{T_1}}{s_{pooled}}$	$SE_{sg} = \sqrt{\frac{2 \cdot (1 - r)}{n} + \frac{(ES_{sg})^2}{2 \cdot n}}$
Natural log of the odds ratio	Effect size for two dichotomous variables with data presented as relative frequencies, e.g., group (control vs. intervention) and success (test passed vs. test failed)	$ES_{LOR} = \log_e\left(\frac{a \cdot d}{b \cdot c}\right)$	$SE_{LOR} = \sqrt{\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d}}$
Olkin-Pratt approach for the product-moment correlation	Association between two continuous variables, e.g., intelligence and learning ability	$ES_{OP_r} = r \cdot \left(1 + \frac{1 - r^2}{2 \cdot (n - 1 - 3)}\right)$	$SE_{OP_r} = \sqrt{(ES_{OP_r})^2 - 1 + \frac{(n-3) \cdot (1 - r^2) \cdot {}_2F_1(1; 1; \frac{n}{2}; 1 - r^2)}{n - 2}}$

ES effect size; *SE* standard error; *sm* standardized mean; *sg* standardized gain; *LOR* log of the odds ratio; OP_r Olkin-Pratt-transformed product-moment correlation; $\bar{X}$ mean of variable *X*; s_{pooled} pooled standard deviation; *N* size of whole sample; *n* size of subsample; G_1 and G_2 Group 1 and Group 2, respectively; T_1 and T_2 Time 1 and Time 2, respectively; *a* frequency in Cell A (1st row, 1st column); *b* frequency in Cell B (1st row, 2nd column); *c* frequency in Cell C (2nd row, 1st column); *d* frequency in Cell D (2nd row, 2nd column); ${}_2F_1$ = Gaussian hypergeometric function (cf. Schulze 2004, formula 3.7)
Source: Lipsey and Wilson 2001, Table 3.2; Schulze 2004.

is due to random error. In random-effect models, in contrast, it is assumed that this variance can also be due to systematic differences between the samples. In most contexts, the random-effect model is more appropriate than the fixed-effects model.

After the decision about the statistical model has been made, the summary effect size and the amount of heterogeneity of the effect sizes can be estimated. The exact estimation of these figures varies between fixed- and random-effect models (for detailed formulas, see Lipsey and Wilson 2001). Significant heterogeneity indicates that additional moderator analyses may be useful to explain some of the differences between the effect sizes. Importantly, the existence of heterogeneity should not be used to decide between a fixed- or random-effect approach, but rather, this decision should be based on theoretical grounds. The goal of moderator analyses is to identify those variables that account for at least some of the differences between effect sizes. Moderator variables can be substantive (e.g., type of intervention, mean age) as well as methodological (e.g., study quality).

Step 6: Report Findings

Meta-analytic findings can be reported in tables or in graphs. Tables are particularly useful to report the effect sizes and other interesting study characteristics of each individual study, as well as for the presentation of moderator analyses. A specific graphical presentation of meta-analytic findings is the forest plot. In this type of plot, the effect sizes of single studies, the summary effect size, and the corresponding confidence intervals are presented. Forest plots can easily be produced with the metafor package in R (Viechtbauer 2010; see below).

Software

Most standard statistical programs can be used to conduct meta-analyses. However, some programs have been developed explicitly for meta-analyses and therefore provide more functionality. For instance, the freely available R package metafor (Viechtbauer 2010) does not only provide functions for different variants of fixed- and random-effect models, but also a number of graphical tools that help to display the findings.

Important Scientific Research and Open Questions

Many studies in the field of learning studies are randomized control trials designed to evaluate the effectiveness of specific interventions, for instance, specific teaching methods. Single evaluation studies are often restricted to specific subgroups (e.g., eighth graders), outcomes (e.g., effects on motivation versus effects on academic test results), and contexts (e.g., number of students in a class). Meta-analyses provide a powerful tool to generalize the effects of specific interventions across different samples, outcomes, and contexts. Moreover, the specific characteristics of single studies can be examined in moderator analyses, for instance in order to determine whether the number of students in the class influences the effect of a specific learning method. Prominent examples are two independent meta-analyses on problem-based learning conducted and published almost simultaneously by Albanese and Mitchell (1993) and Vernon and Blake (1993). In both meta-analyses, it was found that problem-based learning was superior to traditional teaching methods in terms of student satisfaction, but not in terms of academic achievement.

Meta-analyses are also useful to examine individual differences in learning. For instance, Spencer and Raz (1995) aggregated studies comparing the episodic memory capacities of younger and older adults. They found that memory for context is more strongly affected by age than memory for content. Finally, meta-analyses are increasingly used to aggregate the findings of neuroimaging studies. A recent example is a meta-analysis by Wager and Smith (2003) on the representation of different working memory processes in the prefrontal cortex.

In sum, meta-analyses have been and most likely will be highly influential methods to aggregate previous studies, generalize findings, and identify venues for future research on learning.

Cross-References

► Methodologies of Learning Research: Overview

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M

Metric Learning

► Similarity Learning

Microculture of Learning Environments

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Synonyms

Culture-within-a-culture; Subculture

Definition

Microculture of a learning environment includes a common set of shared norms, values, symbols, artifacts, practices, and discourse among a restrictive group of participants in a formal or informal learning setting, face-to-face or online. Comprising a network of meanings, a microculture equips its members with an understanding of what is regarded as acceptable behavior within their community of learners. This is established and communicated through the social and cultural norms of this microculture. Microcultures represent cultures-within-a culture of learning environments, where the members are influenced to a great extent by the norms of the surrounding overall culture (institutional context, e.g., their school) but also, are affected largely by the norms of their unique microculture of their particular community of learners.

Theoretical Background

Much of the research on microcultures of learning environments, in face-to-face and online contexts, has oriented to study classrooms and other learning contexts such as online learning environments as a sociocultural and socio-cognitive activity where thinking and doing are linked in a social practice of participants' community of learners (Brown and Campione 1994). Learning is, then, not located only in individuals' minds, but situated in the physical and social context (Greeno 1989). Thus, the development of expertise is related not only to the nature of an individual's knowledge structures, but also to that person's access to relevant formal and informal cultural knowledge through participating in a community of practice (Lave and Wenger 1991; Wenger 1998). Learning is not only about learning a topic, but also being a member of a collective. Participation in a community of learners brings about a common set of shared norms, values, symbols, artifacts, practices, and discourse. This situated learning approach, in a broad sense, offers tools for analyzing the relation between individual and social dimensions of microculture in learning environments in order to better understand how participants become competent members of their communities of learners and how they learn within this context.

Culture can be approached in both general and specific terms. At a general level, culture may seem relatively consistent but in the representations across individuals and their unique communities, universals tend to give way to diversity. In educational practices, certain common features of classroom culture can be recognized, and certain patterns of social and cultural practices seem to be present, e.g., in classrooms worldwide. However, it is widely acknowledged that every community of learners develops its own culture, its common set of shared norms, values, symbols, practices, artifacts, and discourse, its own microculture that is distinct from the others'. The common characteristics of classroom cultures exist parallel to the emerging microcultures that participants construct within their community of learners.

Microcultures of learning environments are dualities containing two interrelated processes: they are both the medium and outcome of social action. They serve as the medium in the sense that members of the microculture draw on existing cultural norms. That is the adoption by the participants of the shared norms, values, symbols, artifacts, practices, and discourse. Microcultures are also outcomes because the cultural norms exist only if they are invoked and reproduced in social practice by the members. This points to the participation of the members to the development of the shared norms, values, symbols, artifacts, practices, and discourse. A microculture of learning environments is thus at the same time the context and the outcome or product of prevailing social practices; simultaneously given and constructed.

Important Scientific Research and Open Questions

In general, difficulties of studying culture have been widely recognized due to its implicit, complex and overlapping nature. Also, there are many uses and meanings of culture that may not provide a clear foundation for conducting empirical studies in culture. In traditional studies in education, culture has not been under scrutiny, it has been treated as a categorical variable, or the perspective has been relatively restrictive (Gutiérrez 2002). The dual nature of microculture if seen simultaneously as given and as a unique construction of the particular community of learners illuminates well the many complexities and challenges faced in empirical investigations.

Research in microcultures of learning environments has been undertaken, e.g., in the fields of instructional psychology, education, and educational technology. In classroom settings, such studies have been focusing basically on general patterns of classroom microcultures or on domain-specific classroom microcultures, for example, in the fields of mathematics education (e.g., Motierrez Lopez and Allal 2007) and literacy practices (e.g., Gutiérrez 2002), from the perspectives of teaching and learning. It has been studied how different microcultures emerge in classroom settings or, what kind of cultural patterns are present in classroom culture in general terms or in regard to domain-specific microculture. Also, the studies on tensions between the relatively universal and stable normative classroom scripts or practices and the local and unique practices constructed by the members of the learning community are seen critical to better understand individual and social dimensions of learning in diverse learning contexts. This perspective is considered challenging when it comes to the scrutiny of teaching and learning practices, having implications for the design of successful learning environments.

Cross-References

► Learning Environments
► Situated Cognition
► Situated Learning
► Social Learning Theories

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Microdevelopment

► Modeling Microgenetic Data

Microgenetic Analysis

► Microgenetic Method

Microgenetic Method

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Synonyms

Microgenetic analysis

Definition

The microgenetic method is an approach used in cognitive developmental research which allows obtaining detailed data about changes in a particular competence at the moment the change is actually taking place. This approach is characterized by three key properties: (a) observations encompass the entire period of change, starting before the change begins and continuing until the competence has reached a relatively stable state, (b) the density of observations is high relative to the rate of change of the competence under study, and (c) observations are analyzed intensively on an individual and trial-by-trial basis as to understand the process that gives rise to both qualitative and quantitative aspects of change. The second property is especially important. Densely sampling changes while they are occurring provides the temporal resolution needed to understand the process of change.

Theoretical Background

(Cognitive) developmental researchers started adopting the microgenetic method because the standard methods used in developmental psychology, such as the cross-sectional or longitudinal method, did not enable them to study the process of change in great detail. The time between observations of a changing competence in these classical research designs is too widely spaced to yield fine-grained information about the change process. The microgenetic method tries to capture the change process by increasing the density of observations at the moment the change is occurring, resulting in a series of "snapshots" of the phenomenon undergoing the change.

The name as well as the concept of "microgenetic designs" already goes back to the work of Werner in the mid-1920s (Catan 1986). He sought to formulate general developmental laws that would apply to phenomena on all developmental levels (e.g., the acquisition of word meanings in both individual ontogenesis and ethnogenesis of languages). Werner aimed at exploring and testing hypotheses of large-scale developmental processes by creating small-scale or *micro*models of these phenomena. The developmental phenomena of interest were scaled down by artificially provoking and representing the process, its origins (i.e., its *genesis*), and the conditions of its activation and development in a miniaturized, accelerated form. Werner termed this approach the "microgenetic method." Despite the strong pleas in favor of the microgenetic method (e.g., Vygotsky 1978) and its clear advantages, the method was rarely used in the ensuing years. The first publications reporting on microgenetic analyses appeared only in the 1970s and early 1980s (e.g., Karmiloff-Smith and Inhelder 1974; Kuhn and Ho 1980; Wertsch and Hickmann 1987). The number of microgenetic studies has, however, increased rapidly over the last 20 years, and this trend looks set to continue. Probably the most important reason for this increased prevalence is the growing awareness of the unparalleled richness of the data yielded by this method.

In a prototypic microgenetic study, children receive multiple trials of (several versions of) a problem over several testing sessions. The dense sampling of behavior in a transitional period enables researchers to examine, on a trial-by-trial basis, the circumstances that precede a change (e.g., the kind of problems preceding the change), the nature of the change (e.g., whether the child was aware of the change), and how the competence further develops after the change (e.g., whether the change becomes immediately apparent on all following problems or whether it generalizes only gradually).

One of the biggest challenges in conducting a microgenetic study is ensuring that the period of intense sampling over time coincides entirely with the period that the change occurs. There are two ways in which this challenge could be met. One way is to take an everyday task, hypothesize the type of experiences that typically lead to changes in performance on this task, and accelerate the change process by providing a higher concentration of these experiences than would normally occur. A second approach is to present a novel task and to observe children's changing understanding as they interact with it.

Microgenetic studies allow analyzing the change observed along five dimensions (Siegler 2006):

- The *path* of change is the sequence of knowledge states, representations or predominant behaviors that individuals progress through before they have reached full competence. It establishes whether individuals show qualitative changes (i.e., different types of knowledge or ability), quantitative changes (i.e., increases in speed and/or accuracy), or both.
- The *rate* of change involves the amount of time or experience before a new knowledge state, representation, or behavior appears (i.e., *the rate of discovery*), and the amount of time or experience before the new knowledge state, representation, or behavior is implemented consistently across problems within the same domain (i.e., *the rate of uptake*).
- The *breadth* of change refers to the extent to which the new approach is generalized to other problems, tasks, and contexts.
- The *variability* of change refers to intra- as well as inter-individual differences in the path, rate, and breadth of change.
- The *source* of change pertains to the causes that set the change in motion. A wide variety of experiences can evoke change: practice, feedback, direct instruction, social collaboration, requests to explain observations, etc.

Important Scientific Research and Open Questions

Even though the microgenetic method has been applied in diverse age groups, content areas, and settings, the diverse studies incorporating this method have yielded surprisingly consistent findings. Perhaps the most central finding revealed by these studies is the great variability in behavior. In microgenetic research variability is considered as an important phenomenon, rather than as a nuisance to be minimized. Its specific focus on individual-based, process-oriented data allows an identification of the irregular aspects of change. It has been found that variability can occur *within* participants, with individuals successfully using a more advanced approach on a particular problem, but then using a less sophisticated approach on a subsequent presentation of the same or a similar problem. Individuals may also show high variability during certain stages of change but low variability during other stages of change for the same competence. Variability can also be present *between* individuals. Some children may show a gradual, smooth change in a competence, while others show a sudden change. Further, children of the same age may use different approaches to solve the same type of problems. This central finding indicates that the traditional view of development as a transition from one consistent understanding toward another more advanced consistent understanding needs to be refined. It appears that individuals typically use multiple approaches over prolonged periods of time. Consequently, change can be conceived as a gradual and continuous variation in the frequencies of the ways of thinking whereby new ways of thinking are being added and old ones being eliminated (Siegler 1996).

Although the microgenetic method can clearly provide a more detailed description of change based on individual trial-by-trial data than most other methods, it is not clear yet whether it can help in identifying the *mechanisms* underlying change. Obviously, this goal cannot be attained easily since these mechanisms can be described at multiple levels that vary in specificity (e.g., maturation, improved working memory, automatization), time frame (e.g., years, months, days, minutes), and system (e.g., behavioral, computational, neural). Nevertheless, the microgenetic method seems quite promising in this respect because its detailed descriptions of change enable suggesting candidate mechanisms as well as ruling out alternatives. One of the issues that needs to be further explored is whether there exist similarities and differences in how the different aspects of change (i.e., path, rate, breadth, variability, and sources) are involved in various types of acquisitions (e.g., strategies, behaviors, beliefs, skills, knowledge). Another way in which microgenetic data can help specify mechanisms of change is by clearly differentiating the causes of three types of microgenetic change: the discovery of a new skill, the uptake of that skill, and the increased prevalence of this skill with time. It may be that the underlying mechanisms are quite different in the three cases. A third direction that may prove fruitful in illuminating change mechanisms is combining the microgenetic method with neuroimaging techniques. Like the microgenetic method, these techniques can identify and measure change as it occurs. Establishing associations between changes in brain activity and changes in behavior could help identifying the psychological mechanisms underlying these changes.

The microgenetic method is mostly applied to study cognitive development in an experimental context by having an individual child solving problems on its own. However, it still remains to be tested whether the technique can also be applied in a variety of other settings. A first context where microgenetic approaches may lead to new insights are *social settings*. It would be interesting to know (a) whether specific changes in the nature of the social interaction would give rise to changes in cognitive competence and vice versa and (b) the extent to which changes in cognitive competence in a social setting would differ from those during solitary activity. A second environment in which the microgenetic method could make important contributions are *educational settings*. This can be realized by carefully examining the effects of various types of teaching methods, interventions, and feedback on the learning process of children. Third, the microgenetic method may also be very useful in *clinical contexts* where change is frequently the main goal of mental health interventions. The method can offer an approach to examine positive change (i.e., rates of improvements through different treatments or interventions) and detrimental effects (i.e., rates and pathways of symptoms that define disorders). Moreover, the microgenetic method can also be an important diagnostic tool for clinicians. Due to its intensity of repeated observations, it gives participants more opportunities to demonstrate different types of behavior. This enables researchers to observe behaviors that may be less frequent but still within a person's repertoire, revealing the full range of behaviors that an individual can produce. Finally, the microgenetic method could also be applied to study change in *diverse populations*. For example, it could reveal in which of the five aspects of change children with low IQs, high IQs, or specific learning disabilities would differ from their peers.

In sum, the microgenetic method is a promising research tool of broad applicability offering fine-grained information about processes of change.

Microgenetic data give rise to a growing number of mechanistic models of short-term change. Testing whether the mechanisms that produce changes in these models can also account for long-term changes promises to be a particularly exciting frontier in the study of children's learning.

Cross-References

- ► Accelerated Learning
- ► Cognitive Tasks and Learning
- ► Development and Learning
- ► Experimental and Quasi-experimental Designs for Research on Learning
- ► Feedback and Learning
- ► Human Cognition and Learning
- ► Laboratory Learning
- ► Measurement of Change in Learning
- ► Modeling Microgenetic Data
- ► Piaget's Learning Theory
- ► Problem Solving

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Microgenetic Studies

These studies include dense, trial-by-trial observations of learning to assess the mechanisms underlying the process of cognitive change. Microgenetic studies investigate five dimensions of cognitive change: source, path, rate, breadth, and variability.

Microlearning

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Synonyms

Byte-sized learning; Episodic learning; Nano-learning; On-demand learning

Definition

The term *microlearning* has been used since the beginning of the twenty-first century mainly in the context of e-Learning. Commonly it stands for an abbreviated manner of expression for all sorts of short-time learning activities with microcontent. The term is used in many different ways. The spectrum of implicit or explicit definitions ranges from (1) unspecified forms of webspeak about learning by means of digital media and (2) ideological concepts of how learning processes ought to be organized according to the fast-moving world of technology to (3) differentiated conceptualizations of learning processes as related to micro-perspectives in the context of learning, education, and training.

Theoretical Background

From a historical perspective learning in small steps is nothing new. Already the old saying "A journey of thousand miles starts with the first step" which has been ascribed to the Chinese philosopher Lao-Tse (6th or 4th century BCE) can be interpreted as a metaphor for a necessary relationship between single learning steps and long-term learning goals. From a history of education viewpoint many examples for the relevance of "learning in small steps" and also its relation to the learning of structures and complex relationships can be pointed out (cf. Hierdeis 2007).

Whereas implicit conceptualizations of *microlearning* can be traced back throughout history, explicit forms of using the term proliferate at the intersection of the social, educational, and technical after the millennium change. In contrast to explicit concepts of microteaching which have been continuously developed especially in the field of teacher education since the 1960s, *microlearning* is a rather new expression (cf. Hug and Friesen 2009, p. 2). Although it can be conceptualized as counterpart to microteaching, it is rather associated with expressions like “microcontent” or “micromedia,” particularly in the context of Internet parlance in which these expressions are typically used for sets of emerging phenomena at the same time lacking a sharp focus.

The basic idea of designing, using, and reflecting relatively small learning units and short-time learning activities is not limited to a special learning theory. On the contrary, many analytic frameworks for learning offer indications for micro-perspectives on learning without referring to *microlearning* explicitly.

As to defining *microlearning* and related theoretical backgrounds distinguishing between simplex or naïve theories and complex conceptualizations is indicated. In both cases normative and descriptive aspects play a role. However, simplex versions of *microlearning* often carry connotations of ideology as, for example, related to:

- Unspecified necessities of life-long learning in mediatized societies
- On-demand learning needs of workers in a taken for granted “New Work Order”
- Claims of how learning processes ought to be organized according to technological developments like small screens on mobile devices
- Aspirations of representing the crowning achievement after other “learning paradigms”
- The promotion of learning bits and pieces in fragmented lives and lifeworlds as a value in itself.

Although such ideological aspects mainly occur in common sense or market-oriented descriptions, even academic psychological or pedagogical notions about *microlearning* may contain similar elements of ideology.

In recent years, some authors have presented *microlearning* as a relational cross-over concept in the context of technological, societal, and cultural transformation (cf. Hug and Friesen 2009). In order to distinguish it from technology-focused concepts of eLearning, mLearning, distributed learning, or the implementation of ICT in mainstream education, (mediated) learning contexts and cultures as well as layers and perspectives of descriptions are considered of importance. In doing so, many versions and meanings of *microlearning* are taken into account according to the heterogeneity of different domains of reference and application and the selected mode of distinguishing micro-, meso-, and macro-levels (see Table 1).

No matter how learning is conceptualized as a process of

- Building up and organizing knowledge
- Transformation based on processes of meaning-making in specific contexts
- Enabling or leading to relative permanent capacity change beyond "pure" biological maturation or aging

and no matter if we are referring to changes of behavior, attitudes, values, mental abilities, task performance, cognitive structures, emotional reactions, action patterns, or social dynamics, in all cases there is the possibility of addressing micro-, meso-, and macro-aspects of learning (cf. Hug 2005, p. 3 f.).

This meta-model can be interpreted in terms of ecological perspectives as well as learning scapes, spheres, or spaces. However, it offers a manifold of different understandings of *microlearning* as related to learning concepts, situations, arrangements, and contexts. The analytical framework does not suggest a specific concept of *microlearning* per se. It rather opens up various perspectives for understanding, designing, and evaluating processes of *microlearning.*

Among others, key conceptual developments refer to the following aspects (cf. Hug and Friesen 2009, p. 4):

- Concerning *time microlearning* is related to relatively short efforts and low degrees of time consumption both in the sense of measurable and subjective time.
- In terms of *content* it deals with relatively small items or units and rather narrow topics, even

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Microlearning. Table 1 Microlearning–mesolearning–macrolearning (cf. Hug 2005, p. 3)

	Example 1 *Linguistics*	Example 2 *Language learning*	Example 3 *Learning contents*	Example 4 *Course structure*	Example 5 *Competency classification*	Example 6 *Sociology*
Micro level	Single letters	Vocables, phrases, sentences	Learning objects, micro content	Learning objects	Competencies of learners or teachers	Individualized learning
Meso level	Words, letter–figure combinations, sentences	Situations, episodes	Subareas, narrow themes	Topics, lessons	Designing a lecture	Group learning or organizational learning
Macro level	Texts, conversation, linguistic communication	Sociocultural specifics, complex semantics	Topics, subjects	Courses, curricular structures	Designing a curriculum	Learning of generations, learning of societies

though aspects of multiliteracies and multimodalities can play a complex role.

- *Processes* of *microlearning* can be related primarily to formal, informal, or nonformal contexts. It can be designed for corporate learning, for continuing education, or for classroom learning as part of a curricular setting as well as for learning beyond the classroom. Entailing subprocesses may be separate or concurrent, situated or integrated into other activities, and they may follow iterative methods, networked patterns, or certain modes of attention management.
- Its *form* may be described in terms of fragments, facets, episodes, “knowledge nuggets,” skill elements, or more or less loosely linked elements.
- *Microlearning* can be modeled with reference to a range of pedagogies and *learning concepts*, including reflective, pragmatist, conceptionalist, constructivist, connectivist, or behaviorist learning, or action-, task-, exercise-, goal-, or problem-oriented learning.
- Last but not least, *microlearning* can involve the use of different *media technologies* – book printing, radio, film, TV, computer, Internet, and various mobile technologies.

On the one hand, *microlearning* can be described in terms of rather simple markers such as low degrees of time consumption (temporality) and dealing with relatively small items (content). On the other hand, depending on which domain of reference we refer to as “learning” and which perspective we consider of special importance, we mark out an object of study which is then conceptualized and communicated as *microlearning*.

Important Scientific Research and Open Questions

Explicit conceptualizations of *microlearning* in mediatized learning environments are being discussed for a few years now (cf. Gassler 2004). Little basic research has been done so far, and applied research in this field is largely limited to technological issues or mechanical learning (Learning I sensu Gregory Bateson). Moreover, ideological aspects of *microlearning* discourses have rather been celebrated than critically analyzed in terms of learning theory, knowledge integration, didactics, governmentality, or dulling of the mind.

Unsurprisingly, the concept of *microlearning* has been questioned in the sense that learning in small steps would only lead to an aggregation of isolated pieces of information, and that social forms and systems of knowledge could not solely be understood as effects of learning in small steps (cf. Hierdeis 2007, p. 49). Indeed, *microlearning* discourses suggest the clarification and rethinking synthetic and analytic methods of teaching and learning. The same applies to the relation of psychological and pedagogical concepts of learning (cf. Göhlich et al. 2007) as well as to philosophical and sociological approaches to learning in mediated lifeworlds.

Since the concept of *microlearning* does not correspond to a specific learning model, for both, basic and applied research an important task is to sound out viable configurations in the manifold of different options and understandings. If we accept that there is a need for the enhancement of didactical thinking and for rethinking traditional learning models in view of media-cultural dynamics, such configurations could be useful. There are quite a few general models which can be used as starting points in the context of linking together microlearning elements and micro-, meso-, and macro-levels. Among them there are the following (cf. Hug and Friesen 2009, p. 5):

- In the conglomerate model diverse micro elements can be arrayed as a kind of assortment of learning products and processes.
- In the emergence model new phenomena, coherent structures and qualities evolve from and between microlearning elements themselves. Novel patterns arise out of a multiplicity of relatively simple interactions or steps in the dynamic process of self-organization.
- *Microlearning* processes can be embedded in single- and double-loop learning strategies when developing various levels of knowledge and modes of knowing, and promoting the (cognitive) activities necessary for this (cf. Peschl 2010).
- According to the medium/form distinction learning results can be understood as form in a medium of loosely coupled elements. Because any given form can act as medium on another level, layers and layers of distinctions can be described in flexible ways.
- Principles of bricolage such as there are openness, agility, and flexibility in thinking and acting, dealing with heterogeneous matters and limited resources, spatiotemporal anchoring of actions, have been applied to educational contexts in various ways. They can be reappraised in the context of learning and corresponding micro-, meso-, and macro-perspectives.

Future research might attempt to clarify how these concepts and models can be applied to issues of *microlearning* and how they can allow for episodic structures of learning in fruitful ways. While pessimistic voices tend to claim that *microlearning* is the problem considering itself to be the solution, optimistic voices might emphasize that the long journey of transcending existing orders and reframing learning cultures in the age of digitization starts with micro-steps.

Cross-References

- ► Ecology of Learning
- ► Episodic Learning
- ► Knowledge Integration
- ► Microculture of Learning Environments
- ► Micro-genetic Analysis of Learning
- ► Mobile Learning
- ► Multimedia Learning
- ► Multimodal Learning Through Media

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Micro-processes of Attention

► Role of Attention Triangulation in Organizational Learning Processes

Milgram, Stanley (1933–1984)

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Life Data

Stanley Milgram was born in 1933 in New York City. In 1954, he received his bachelor's degree in political science from Queens College, New York. He applied for a Ph.D. program in social psychology at Harvard University, but was initially rejected due to an insufficient background in psychology. He was finally accepted to Harvard in 1954 and received a Ph.D. in social psychology in 1960. However, Milgram's relationship with Harvard remained problematic because he was denied tenure there – probably due to his controversial experimental research. Instead, he became a tenured full professor at the City University of New York Graduate Center. Milgram died of a heart attack on 20 December 1984.

Theoretical Background

As a social psychologist Stanley Milgram became popular due to his controversial experimental study on obedience to authority – now known simply as the Milgram Experiment. This study was conducted in the 1960s and was inspired by the trial of Adolf Eichmann and the Nazi Holocaust. The central idea was to demonstrate experimentally the strong relationship between obedience and authority. In 1963, Milgram submitted the results of his experiment in the article "Behavioral Study of Obedience," with the result that a controversial debate began concerning the ethics of the Milgram Experiment (Baumrind 1964). Finally, in 1974, Milgram succeeded in publishing his experimental study and received the annual social psychology award for his excellent work on social aspects of obedience. The results of the Milgram Experiment were later used to explain the My Lai Massacre in 1968 as well as more general phenomena such as social aspects of authority in military training, depersonalization on the basis of racial and cultural differences, and so on.

Since its publication, the Milgram Experiment has been criticized as unethical as it caused enormous stress in the participants. There is still an ongoing debate on the experiment in the psychological community, where many see it as providing a vindication of torture and murder resulting from learned obedience to authority.

However, the study on obedience to authority is only one example of Milgram's notorious methodology of experimental research. Another example is the *small-world experiment* conducted in 1967. In this experiment, Milgram sent several packages to 160 randomly assigned people living in Omaha, Nebraska, and asked them to forward the package to a friend, who was in turn asked to forward the package to another friend, and so on. In the end, the package was supposed to reach the final addressee, a stockbroker from Boston, Massachusetts. Milgram reported "six degrees" of forwarding, but he only traced a few of the packages. As a consequence, the "six degrees" theory has been criticized by numerous psychologists. Nevertheless, the results of the small-world experiment remain impressive. Milgram used the same method in the "lost letter" experiment he conducted a couple of years before. In this study, Milgram planted several sealed and stamped letters in public places, addressed to individuals and favorable organizations, such as medical research institutes, as well as to politically stigmatized organizations such as "Friends of the Nazi Party." Milgram found that most of the letters addressed to individuals and favorable organizations were mailed, while most of those addressed to stigmatized organizations were not. However, 36 years after Milgram's small-world experiment, Dodds, Muhamad, and Watts (2003) replicated the study with 60,000 email users who were asked to reach 1 of 18 target individuals in 13 countries by forwarding messages to acquaintances. The findings show that Milgram's results are solid with regard to the six degrees of separation.

Contribution(s) to the Field of Learning

▸ We didn't need Milgram to tell us we have a tendency to obey orders. What we didn't know before Milgram's experiments is just how powerful this tendency is. And having been enlightened about our extreme readiness to obey authorities, we can try to take steps to guard ourselves against unwelcome or reprehensible commands (Blass 2002, p. 73).

Milgram's contributions were remarkably numerous and varied during his career: He conducted the experiments that led to the phrase "six degrees of separation" and devised methodological innovations such as the "lost letter" technique. But it is the obedience experiments for which Milgram will always be remembered, for better or for worse. Indeed, the Milgram Experiment has proved to be the most influential and controversial experiment in modern social psychology. It has affected specific fields of interest, such as law, business, medicine, and the military. Plays, films, and songs have been based on the experiments, and well-known authors such as Doris Lessing and Arthur Koestler have written about them at length.

Blass (1999, 2004), author of Milgram's biography, reviewed all the research on and social implications of Milgram's study. In general, he found that the results of replications have remained consistent and relatively unchanged over the past 45 years, which may be surprising when one considers that many are aware of Milgram's studies and the extreme results that blind obedience can lead to. Milgram's contribution did not consist in showing that human beings obey authority, but in demonstrating how powerful and potentially dangerous this predisposition is (Milgram 1974).

Milgram's experiments are usually discussed in the context of social psychology and the investigation of people's situation-dependent behavior. However, the study on obedience to authority in particular can be considered as a substantial contribution to the study of learning in stressful situations. Clearly, the research design corresponds to a large extent to a learning experiment which works with a "teacher" (i.e., the true participant), a "learner" (i.e., the confederate of the experimenter), and an experimenter, who was played in the original study (Milgram 1963) by a high-school biology teacher. The essence of the study was really to examine how people learn to obey authority. The participants were told they were involved in a study regarding the relationship between punishment and learning, and they thus followed the experimenter's order to punish learners due to their faults in memorizing various word pairs.

Milgram's experiments also had an impact on the ethics of research. Today, many people believe that a psychological study like the Milgram Experiment would never be allowed in most countries due to ethical considerations. But ethical constraints do not seem to stop the entertainment industry. In consequence, it is easy to find numerous replications of the Milgram Experiment on obedience to authority.

Cross-References

► Learning of Obedience to Authority

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Mill, John Stuart (1806–1873)

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Life Dates

John Stuart Mill (May 20, 1806–May 8, 1873) was an influential English public intellectual. He named *Utilitarianism* (1861) as a school of thought and is most famous for his systematic explanation and defense of the market place of ideas in *On Liberty* (1859). He was a tireless and effective *reformer of the world* (in his own words) through his essays and parliamentary testimony, later serving a term in the House of Commons. He advocated free public education, but he himself was schooled at home by his father, James Mill. Throughout his life, he championed progressive causes including women's rights. Other important titles are *Considerations on Representative Government* (1861) and *A System of Logic* (1843).

Theoretical Background

James Mill, influenced by his close personal friend Jeremy Bentham and reading Jean-Jacques Rousseau's

Émile, decided himself to educate his eldest son, John Stuart Mill. James Mill believed that the mind was plastic and that nurture – associationism – determined its shape. In later life, John Stuart Mill attributed his achievements to his unusual and remarkable education, and not to any special ability, which proved how much more can be learned than usually is in formal education.

Our knowledge of Mill's education comes from his *Autobiography* (1874) published after his death. Like Mozart, the Young Mill was a prodigy. He had learned to read Greek at age three. At eight he had mastered Latin. Algebra, geometry, and mathematics followed. He read copiously starting with Aesop's *Fables*, Lucien's *Histories*, Plutarch's *Lives*, and Plato's *Dialogues*. He summarized his reading to his father on long walks and in written notes. As a teenager, he contributed to James Mill's publications and edited some of Bentham's. The boy Mill is glimpsed in his fondness for stirring tales of the sailors Francis Drake and James Cook, and his appetite for Daniel Defoe's *Robinson Crusoe* (1719). Curiously, this is a book that Rousseau permitted Émile as a testament of self-reliance. His father accepted this boyish reading provided the curriculum came first. Young Mill studied every day with his father and was carefully shielded from contact with other children, apart from his own siblings, just as was Rousseau's Émile. Mill described himself as physically inept. Because of this isolation, Mill had no way of knowing that he was different until later.

At about eight, his father made him schoolmaster for his siblings (eight in all), and though we know little of how this worked, John Stuart Mill says he was a failure at it. Yet, it continued until Mill was in his 30s. He was often required to spend his time in this pursuit rather than traveling, socializing, or even reading.

It was only as a teenager, after a sojourn in France, that nature seems to intrude on nurture. He began to read romantic poetry and to write it. While the adult Mill had colleagues in his many causes, there is scant indication that he had any friends. The only woman in his life (his mother is not mentioned in the published *Autobiography*) is Harriet Taylor who befriended him and who married him 20 years later.

James Mill said he educated Young John to advocate Utilitarianism after he and Jeremy Bentham died. For that reason, some of John Stuart Mill's contemporaries referred to him as a *manufactured man*. One could say that John Stuart Mill had an education as rigorous as Plato asserted for philosophers to be kings and just as focused. The Young Mill was subjected to a very strict program; there is never a hint of affection for his father in the *Autobiography*. Whatever the elder Mill's intention, John Stuart Mill was a remarkable man. He wrote essays and reviews, and then books from his teenage years. His collected works run to more than 30 substantial volumes. The quantity is impressive and so is the quality. Mill's essays are trenchant, clear, and closely argued.

Among Mill's many works, his *A System of Logic* (1843) codified a comparative approach to inductive reasoning, and has an important place in the evolution of social science. It details five kinds of comparisons: agreement, difference, mixed agreement and difference, residue, and concomitant variation. These comparisons lead to conclusions about causation.

Contribution(s) to the Field of Learning

Mill did not attend a university yet has had more impact on universities than many a distinguished professor. His essays, reviews, and books had such a readership in his day that they became set reading in the historic universities Oxford and Cambridge. His advocacy of free public education also convinced many others in the Victorian Age to accept it. He was a formidable advocate of the franchise for women.

But there is no doubt that his greatest enduring influence was through utilitarianism. He was a *public intellectual* long before that term gained currency. On utilitarian grounds, he advocated a series of causes through essays and reviews read by the educated public of Victorian England. Moreover, he testified before parliamentary committees where his formidable intellect proved more than a match for parliamentarians who mocked this *book man*. Among the causes he championed were public education, hygiene including sewers, equality of women, extension of the franchise, civil service recruitment on merit rather than pedigree, and the like. He inspired others to follow in utilitarianism, making a self-conscious school of thought, which continues to this day. Such a self-conscious school of thought is a rarity in the English-speaking world. One such exponent was Henry Sidgwick who continued Mill's work as a public advocate for education in particular.

Mill also inspired ranks of other individuals to see the practical and moral value of education. His role in providing a compelling justification for higher learning was recognized in 1867 when he was made rector of Saint Andrews University. In his inaugural address, he argued that literature and science were both necessary to an educated mind, whereas the general view at the time was that they were at least competitors if not adversaries. Mill placed value on the capacity of the individual, developed through education, not lineage or natural endowments in his support for civil service reforms and the equality of women. He argued the case for civic education, as the foundation to electoral democracy, throughout his *Consideration on Representative Government* (1861).

A System of Logic (1843) was one of the first and most cogent statements of methodology in the study of society. It did much to elevate the social sciences both directly by equipping students of society with a framework of analysis and indirectly by impressing upon its readers the value of conclusion drawn from such reasoning.

Finally, his own education stands as an example of the application of a theory of learning, associationism, in nearly laboratory conditions. It is an intriguing example of the intersection of nature and nurture.

Cross-References

► Associationism
► Associative Learning
► Dewey, John (1858–1952)
► Plato (429–347 BC)

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Mimicry

► Repetition and Imitation: Opportunities for Learning

Mimicry in Social Interaction: Its Effect on Learning

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Synonyms

Behavioral mimicry; Chameleon effect; Postural synchrony; Verbal mimicry

Definition

Mimicry is an automatic and non-conscious process that occurs in many circumstances and in a wide variety of situations. According to Chartrand and van Baaren (2009), there are several theories of mimicry. Studies have demonstrated that mimicry is a communication tool used to create and regulate social interactions and show others that you understand them. It can truly be called "social glue" which helps to create strong ties and relationships between individuals. According to Chartrand and Bargh (1999), one of the key mechanisms of imitation is the desire for affiliation with the subject with whom one interacts. It seems that mimicry is an effective tool not only to create ties and social relationships, but also for maintaining them. A great deal of research has shown that non-conscious mimicry comes from the automatic link between perception and behavior. According to Bargh et al. (1996), the mere perception of the behavior of another person increases the probability that you will produce the very same behavior. Thus, the fact of seeing someone do something activates corresponding behavioral representations, which in turn induce a higher probability that you will also produce this behavior. The discovery of mirror neurons has argued in favor of a direct link between perception and behavior. Several studies show that seeing someone do something causes the same neurological activations as doing the action oneself would cause.

Important Scientific Research and Open Questions

Mimicry has been noted to have an effect on social judgments; you like a person who imitates you more than if he/she did not imitate you. One perceives someone who imitates him/her as more friendly (Chartrand

and Bargh 1999). Other studies confirm that interpersonal interactions are considered as more pleasant when you are mimicked and also when you mimic. Mimicry also leads individuals to perceiving themselves as being closer. These effects of mimicry on judgments and social relationships seem to come from the fact that being imitated increases the feeling of familiarity toward the mimicker (Guéguen et al. 2009). In a longitudinal research involving observation between students and teachers, LaFrance (1979) observed that the degree of synchrony of nonverbal behaviors and verbal expressions in the teacher–student dyad is a predictor of the quality of the relationship between two people.

In a second study, LaFrance (1982) showed that students tend to mimic the posture of their teacher and that the level of mimicry of the latter is positively correlated with the existing ties between him/her and the students. A recent study (Martin 2010) has shown that children feel more favorably toward an adult who mimics them than do the children who are not mimicked. Indeed, when they are mimicked, children feel more comfortable with adults, they report that they have understood better and have been better understood by him/her. Finally, children who are mimicked take more pleasure in interacting with him/her.

Many research studies have shown that mimicry causes more prosocial behaviors. Mimickees are more altruistic toward mimickers. Mimickees are also more altruistic toward people in general, even other individuals who are not mimickers. It, therefore, seems that being mimicked increases the likelihood that individuals will show altruistic behavior toward other individuals (who mimic or not).

Mimicry increases the perceived trust between the partners. We observed an effect of mimicry on the negotiation process. Indeed, negotiators using a strategy of imitation obtain more information from the other party. The authors explain this effect by the climate of confidence engendered by mimicry. Martin (2010) shows that children who are verbally mimicked by an adult give him/her more confidence by agreeing to tell him/her a secret or by agreeing to tell him/her something mischievous that they have done.

Other studies have examined the effect of mimicry on self-regulation and social coordination and have noticed a high increase in the mobilization of cognitive resources. The capacity for self-regulation is also improved, which in turn results in greater self-control and finally more ability to perform one's own actions. They find that mimicry leads to the perception of high social coordination and thus better social regulation. In many researches, subjects who have previously been mimicked achieve a better score on the task of self-regulation; they also report eating less junk food and procrastinate less than those who are not emulated. In his thesis, Kouzakova (2009) also found that mimicry leads to better cognitive functioning in mimickees. The author shows that the subjects who have been mimicked have a better score on the Stroop task than those who were not mimicked (who indeed are less successful than the control group). The results also show that subjects who are mimicked have better verbal fluency (better access to the vocabulary in memory).

Martin (2010) showed that children who have previously been (verbally) mimicked store more information in a text submitted by the experimenter mimickers and make fewer mistakes than those who had not been mimicked. It also seems that children who are mimicked pay more attention to the documents provided by the experimenter when the latter had previously mimicked them.

Cross-References

▶ Attention and Implicit Learning
▶ Climate of Learning
▶ Cognitive and Affective Learning Strategies
▶ Education of Teacher Educators
▶ Self-Esteem and Learning

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Mindfulness and Meditation

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Synonyms

Attention regulation; Attention training; Contemplation; Contemplative science; Prayer; Relaxation response

Definition

In its most universal sense, *meditation is a mental discipline involving attention regulation.* Attention regulation or training involves developing the capacity to be aware of where the attention is being directed and to discerningly choose the preferred object of attention. The many varieties of meditation can be further defined according to the *object of attention* or the *objective of the practice.* For example, attention can be focused on the bodily senses or the breath as in mindfulness meditation, a mantra, affirmation or prayer, a mental image as in imagery-based practices, an underlying stillness beneath the thinking mind, or a thought or question as in reflective-based practices. In meditative practices that utilize a more open state of awareness, the attention is not selectively given to any particular object. The objectives of meditation practice include becoming more in touch with the present moment, spiritual realization, attaining stillness, peace, unity, insight or transcendence, or for health-based reasons such as in the management of mental or physical health problems. The objects of attention and objectives of the practice overlap and are not mutually exclusive.

Theoretical Background

Meditative or contemplative practices of one form or another have a long history in most if not all cultures. Such practices were largely used with the aim of attaining spiritual insight or experience with secondary psychological or physical benefits seen as desirable side effects indicating a reduction of suffering. In the modern context, meditation is attracting considerable interest in various scientific and clinical disciplines on the back of recent research findings. The investigation of the pragmatic uses or beneficial side effects of meditation has now attracted a considerable level of attention in the scientific and lay communities.

More recently, there is an interesting and important fusion between philosophical insight from ancient wisdom traditions and modern science and psychology. Although many wisdom traditions have made valuable contributions to this field, it is probably the cross-pollination of mindfulness meditation, Buddhism, and contemplative science which has made the greatest single contribution in the modern day.

Most wisdom traditions have historically adopted a metaphysical understanding of the human being where consciousness is the primary reality, and the mind is secondary, i.e., it arises from and is enlivened by consciousness. The body is therefore tertiary and arises from the organizing intelligence of the mind implicit in the complex structure and function of the physical world. The predominant paradigm of science in recent decades however has been far more materialist in its focus where the physical world is seen as primary and mind is secondary, i.e., it is the product rather than the cause of neural activity. Consciousness is tertiary being the product of a high level of neuronal sophistication. Although this age-old metaphysical debate will not be resolved here, it is difficult to avoid the fact that the study of the contemplative sciences has opened up many philosophical and scientific questions about the nature of consciousness, mind, and the physical world.

Psychology naturally focuses its study on the mind and the discipline of mind–body medicine focuses its attention on the links between psychological states and the influence they exert over the body. The investigation of the meditative or contemplative sciences however has enriched both these disciplines by investigating the influence of consciousness or attention on psychological and physical states and functioning. It may be that the use of consciousness is the single most important factor for well-being and purposeful living.

In large part, psychology has tended to view the "self" as the sum total of the contents and dispositions of the mind. Thus, personality and behavior can be seen as mostly fixed after early development as the product of genetic factors, upbringing, and conditioning. The practice of meditation however provides the opportunity to view the ephemeral experiences of the body (sensations) and mind (thoughts and feelings) from a more objective perspective. When the inherently impermanent experiences of the mind and body are viewed from a more stable and permanent perspective of the non-attached observer, then one's relationship to them begins to change. Metacognition is the term commonly used to describe the capacity to stand back from thoughts and not see them as facts or integral to the self but rather as transitory events which can be viewed from a point of non-attached witnessing or "being." This enhances cognitive flexibility and adaptability. The realization of this perspective is not so much a matter of belief but more a matter of direct experience. To the meditative traditions, discussion about the theory of meditation in the absence of direct experience is ungrounded and pointless.

Thus, from a meditative perspective, "self" is not so much the witnessed and tangible events of body and mind, but more the intangible witnessing awareness itself. Freedom from the suffering associated with self-identification with pleasant and unpleasant experiences in body and mind, whether it be physical pain, anxiety, or even depression, is not so much through the capacity to remove or obscure them but rather the transcendence of them through the detached witnessing and nonresistance of them. Relaxation would therefore be seen not so much as a prerequisite for successful meditation practice but more as a side effect of attention training and non-attachment.

Another essential tenet of meditation or mindfulness training is that the present moment is the only one which can lay a valid claim to reality. Although one's present moment experience may be the product of past events and actions, and although one's present moment decisions and actions may lay down the foundations for future experiences, past and future per se do not exist other than as mental projections in the present moment. When given attention, such projections can filter and distort present moment experiences. Hence, stress, anxiety, or depression may be far more commonly the product of discursive and distracted *default mental activity* – whether it is given the name of worry, rumination, replaying, or catastrophizing – rather than a clear, accurate, and objective perception of present moment "reality."

The principles of meditation practices and the insights gained from them have been incorporated into a range of psychotherapy models. Most of these have evolved from mindfulness and many are inspired by Jon Kabat-Zinn's Mindfulness-Based Stress Reducation (MBSR) originally developed at the University of Massachusetts. The psychologists and researchers Teasdale, Segal and Williams adapted a number of these principles and developed Mindfulness-Based Cognitive Therapy (MBCT). Other forms of psychotherapy such as Acceptance Commitment Therapy (ACT) and Dialectical Behavior Therapy (DBT) are not wholly based upon mindfulness but utilize mindfulness principles and practices as a core component of their approaches.

The sitting practice is sometimes called the formal practice of meditation but the formal practice is most useful if it is seen as a method of training oneself to be mindful, present, and attentive in daily life, sometimes called the informal practice. Thus, the benefits of meditation do not just make themselves known at the time of the practice but in daily life also. In other words, the benefits do not so much accrue from the occasional experience of a more mindful *state* but from the disposition or *trait* of being more mindful in daily life.

As has been previously mentioned, meditation practices all involve training attention toward one object or another but vary according to the objects employed. The senses are the mainstay of attention training in mindfulness practice where the attention can either be moved through various parts of the body – the "body scan" – or rested with the sensation of the breath entering and leaving through the nose or at the chest or diaphragm. Other sensory input can be employed such as the hearing and sight or even taste and smell to help anchor the attention to the present moment.

In mindfulness practice, the meditation process does not just involve the training of attention but also the cultivation of an attitude of openness, acceptance non-judgmentality. There is no attempt to exclude other potential objects of attention such as thoughts, sensations, or external events, nor is there an attempt to preferentially experience positive, desired, or pleasant experiences and exclude negative, undesired, or unpleasant ones. An attitude of equanimity and non-reactivity to passing experiences is cultivated. Attitude is crucial because it determines whether the object of experience becomes a magnet for the attention through either attraction or aversion and thereby a potential source of compulsion or suffering. Although a nonjudgmental attitude is cultivated, that does not mean that the person does not develop discernment about what is or is not worth giving attention to.

Important Scientific Research and Open Questions

Much of the original research on meditation was performed on Progressive Muscle Relaxation (PMR) and a mantra-based technique called Transcendental Meditation (TM). This early work looked at the biochemical and physiological effects associated with the *relaxation response*, a term coined by Herbert Benson in the 1970s to indicate the opposite of the "stress" or "fight or flight" response (Benson 1975). The markers of the relaxation response include reductions in blood pressure, pulse rate, catechol output, galvanic skin resistance, metabolic rate, thyroid hormones, and cortisol levels as well as electroencephalogram (EEG) changes such as increases in alpha wave activity and EEG coherence. Psychological effects noted included improvements in concentration and reductions in stress and anxiety. Long-term follow-up indicates economic benefits with life insurance companies finding reductions in health-care utilization.

Jon Kabat-Zinn's work in the 1980s looked at the impact of MBSR for patients with anxiety, stress, panic disorder, and severe chronic pain (Kabat-Zinn et al. 1987). This work was the main stimulus for Teasdale and colleague's more recent trials which demonstrate the impact of MBCT in reducing relapse rates for patients with multiple previous episodes of depression (Teasdale et al. 2000). These findings have probably stimulated more interest among clinicians and the public than any other single piece of research, and have catalyzed a rapid expansion of applications for enhancing emotional regulation, emotional intelligence and compassion, and managing other mental health problems such as anxiety, substance abuse, and eating disorders.

Emergent fields of integrated science are breaking down many longstanding beliefs about the fixity of the structure and function of the brain and genetic makeup. These fields include the role of mindfulness meditation in neuroscience and its effects on neuroplasticity, thickening of the cerebral cortex (particularly in the regions of the prefrontal cortex and hippocampus), and possible neurogenesis (the capacity of the brain to generate new neurones) (Lazar et al 2005). The potential for the prevention and management of dementia is yet to be fully tested. Interesting correlations have also been noted by Davidson and colleagues (Davidson et al. 2003). Mindfulness training was found to produce improvements in the management of daily stress, prefrontal cortex functioning, and immune function. Most recently, a body of evidence building indicates that dealing poorly with chronic stressors and a disposition toward pessimism accelerates cellular aging at a genetic level, whereas mindfulness training may have an effect on slowing genetic aging as indicated by telomere length and enhanced genetic repair via increased telomerase activity (Epel et al. 2009). The implications for the development and progression of chronic diseases are significant. This work makes an important contribution to the field of epigenetics (i.e., that the expression of genotype is influenced by a range of lifestyle, psychological, and environmental factors).

The full clinical potential for meditation, generally, and mindfulness, in particular, to enhance well-being and prevent, slow, and even reverse chronic disease processes is far from known. If recent indications from the fields of neuroscience, genetics, and immunology are anything to go by, then this is a direction of research and clinical practice that is deserving of the significant attention it is now receiving. Organizations such as the Mind and Life Institute (http://www.mindandlife.org/) have been helping to stimulate interesting and mutually valuable dialogue between wisdom and contemplative traditions and modern science, and challenging humankind to reconsider the way it looks at consciousness, mind, brain, body, and genetics.

Cross-References

► Attention, Memory, and Meditation
► Behavior Modification, Behavior Therapy, Applied Behavior Analysis and Learning
► Emotional Intelligence
► Emotion Regulation
► Mental Imagery
► Metacognition and Learning

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Mindreading

▶ Theory of Mind in Animals

Mindset

▶ Attitudes – Formation and Change

Miniature Language

▶ Infant Artificial Language Learning

Minimal Self

▶ Development of Self-consciousness

Mirror Neuron

A mirror neuron, found in the brains of primates, humans, and other species, is a specific kind of neuron that fires both when an animal acts and when the animal observes the action performed by another, in effect "mirroring" the behavior of the other. The mirror neuron system in humans allows for human empathy and enables direct social learning.

Misconceptions

▶ Preconceptions and Learning

Mislearning

▶ Non-learning

Mixed eLearning

▶ Blended Learning

Mixed Methods Research on Learning

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Synonyms

Blended research on learning; Mixed research on learning; Multimethod research on learning

Definition

Mixed methods research (MMR) on learning combines quantitative and qualitative approaches to provide a broader picture of the phenomenon being studied and/or corroborations of results. In MMR any feature of quantitative and qualitative research (e.g., objectives, data type, instruments, data analysis) can be combined at any stage of the mixed research.

Theoretical Background

In the methodological literature of the social sciences the idea of combining different methods within the same study can be traced back to Campbell and Fiske's 1959 article on convergent and discriminant validation by the multitrait-multimethod matrix. However, according to Johnson et al. (2007), the specific idea of blending *qualitative* and *quantitative* methods while studying the same phenomenon first appeared in Denzin's 1978 book "The research act: a theoretical introduction to research methods." The practice of combining qualitative and quantitative methods has changed a great deal over the years and numerous mixed method research designs have been proposed.

With a view to integrating the existing classifications, Leech and Onwuegbuzie (2009) suggested a three dimensional typology of mixed method research designs. The first dimension of this typology is the *level of mixing* that distinguishes between fully mixed methods and partially mixed methods. Fully mixed methods combine quantitative and qualitative techniques within or across one or more stages of the research process (i.e., research objectives, type of data and operations, type of analysis and type of inferences). For example in the same study there might be the presence of both qualitative objectives (e.g., free exploration) and quantitative objectives (e.g., prediction), data collection using qualitative instruments (e.g., open interviews) and quantitative instruments (e.g., closed answers to a questionnaire), as well as qualitative analysis (e.g., coding) and quantitative analysis (e.g., inferential statistics). Partially mixed methods, on the other hand, do not mix quantitative and qualitative components within or across stages: each component is performed separately and it is mixed only when the results are discussed and interpreted. The second dimension of the proposed mixed method research typology is *time orientation* since the quantitative and qualitative methods can either be concurrent (i.e., applied at the same time) or sequential (i.e., taking place one after the other). The third and last dimension is *emphasis of approaches*, which establishes whether qualitative methods and quantitative methods have the same importance or if there is a prevalence of one over the other.

In mixed methods research, a specific definition of the various components of a research process, such as sampling, data collection, data analysis and type of inferences, has been proposed. Mixed methods *sampling* (Teddlie and Yu 2007) involves combining quantitative sampling, in which the probability of the inclusion of a population's case is known, with qualitative techniques such as purposive sampling, in which the units are selected according to the specific aim of the study rather than according to a statistical criterion. Mixed methods *data collection* involves the gathering of qualitative information, such as textual data from interviews or unstructured observational data, as well as quantitative information, such as the closed answers to a questionnaire.

According to Teddlie and Tashakkori (2009), the main types of mixed method *data analysis* techniques are as follows:

– Parallel mixed data analysis. In this case, there is a separate analysis of qualitative and quantitative data, following which the results are combined into meta-inferences.
– Conversion mixed data analysis. This occurs when qualitative data are converted into quantitative data or vice versa. The "quantifying" of qualitative data usually refers to the process of coding data and then converting codes into numbers, while the "qualitizing" of quantitative data generally refers to the elaboration of typologies on the basis of numerical data by means of cluster analysis or other statistical techniques.
– Sequential mixed data analysis. This takes place when the qualitative and quantitative parts of a study occur at different moments. For example, in qualitative to quantitative analysis a typology of subjects is generated from the qualitative data and those distinct groups are then compared using the quantitative data. In quantitative to qualitative analysis, subjects who have high scores on a test (quantitative analysis) can be successively interviewed and the more detailed qualitative data can then be analyzed to search for factors linked to their high test scores. In iterative sequential mixed analysis, the data comes from studies that have more than two phases and there is the possibility of various combinations of qualitative and qualitative stages of analysis.
– Multilevel data analysis. When studying settings with a hierarchical structure, such as students who are grouped into schools, qualitative and quantitative techniques can be used at different levels. For example, a qualitative method could be adopted to

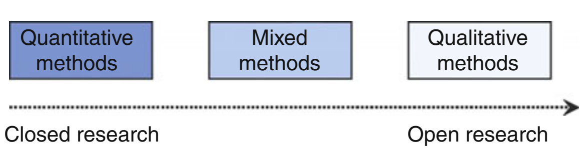
analyze school documentation and teacher interviews (school level) and a quantitative method could be used to analyze students' answers to a closed questionnaire analysis (pupil level).

- Fully integrated data analysis. In this case, qualitative and quantitative analysis of data is combined in an interactive, interrelated, and iterative process.
- Application of analytical techniques from one tradition to another. An example of this is the use of matrices, which are typical of quantitative methods in the context of qualitative research.

As regards inferences in mixed methods research, Morgan (2007) describes the qualitative interpretation as inductive and subjective, while the quantitative interpretation is deductive and objective. The author proposes a pragmatic approach that is based on abduction, a form of reasoning that moves back and forth between induction and deduction and intersubjectivity, in a process of communication and shared meaning.

There has been much theoretical reflection on the relation of mixed method research to qualitative and quantitative research. One way to think of this problem is to consider the quantitative and qualitative approach as being at the opposite ends of a continuum defined by the degree of "openness" of the study in question (Fig. 1).

Quantitative research can be placed at the beginning of the continuum, where the maximum degree of closure is present. Quantitative research can be considered as "closed" since it tests hypotheses (e.g., by means of an experiment) or explores a specific field (e.g., a sample survey on students' attitudes toward school) by collecting *structured data* referring to variables with values that are determined and closed a priori by means of the operational definitions of the constructs studied. In other words, in quantitative research, the variables to be studied and their range of values are already known before the data is collected, and in this sense it is a closed type of research.



Mixed Methods Research on Learning. Fig. 1 The position of MMR between open and closed research

On the other hand, qualitative research may be considered as "open" because it explores an area or tests hypotheses on the basis of unstructured data, without the constraint of having to operationally define what is studied. Qualitative research uses data collection techniques (e.g., open interviews and unstructured observation) that do not completely define a priori the variables and their values, and this may lead to the discovery of new information and knowledge. In this sense, qualitative research can be considered as "open." Mixed method research combines, to varying degrees, the open approach of qualitative research and the closed approach of quantitative research, leading to new possibilities and problems. For example (Alivernini et al. 2008), in a single mixed methods study, it is possible to:

(a) Discover aspects and properties of a phenomenon that are not predictable a priori by the researcher (this is not possible in pure quantitative research)
(b) Test theories and hypotheses upon the phenomenon itself by means of consolidated methodological and statistical procedures (this is not possible in pure qualitative research)
(c) Combine the results into a single interpretative framework

Important Scientific Research and Open Questions

Since mixed methods research involves mixing elements that are characteristic of quantitative methodology with other components that are considered specific to qualitative research, there are many issues connected to the unfinished debate regarding the differences between the two methodologies.

Table 1 shows specific distinctions that, over time, have been suggested in the literature on this topic by various authors. All of these items represent therefore elements that could be combined in a mixed methods study, if one agrees with the proposed differences.

The problem is that the literature regarding the features of quantitative and qualitative methodology is not in agreement and many of the differences listed in the table are quite controversial. For example, as regards the object of study, some authors argue that qualitative research studies subjective meanings (Hammersley 1999), while quantitative research focuses on behaviors. Nevertheless many quantitative researchers might well affirm that they too frequently study subjective meanings:

Mixed Methods Research on Learning. Table 1 Items that could be hypothetically mixed in an MMR study

Aspects of the research	Presumed features of qualitative and quantitative research	
	Qualitative research	*Quantitative research*
Object of study	Nature of things	Quantity of things
	Meanings	Behaviors
	Phenomena that occur naturally	Artificial settings
General purpose of the research	Exploration	Testing hypotheses
	Idiographic	Nomothetic
	To make a theory emerge	Testing a theory
Techniques of investigation and type of data	Participatory observation	Experiment
	Open interview	Sample survey
	Closeness of the researcher	Distance of the researcher
	Natural data	Artificial data
	Rich data	Reliable data
	Words	Numbers
Data analysis and display of results	Coding	Statistics
	Narrations	Tables and figures with numbers

in fact sample surveys that investigate the attitudes, personal values, and subjective perceptions of certain groups of people are common. Another way to distinguish between quantitative and qualitative research is to maintain that the first deals with the quantification of a phenomenon and uses numbers and statistics, while the second focuses on the actual nature or essence of a phenomenon and uses words and various other narrative means. If this is so, the two approaches may be combined within mixed methods research in order to obtain a fuller picture of the phenomenon studied. The idea that qualitative research does not use forms of quantification is, however, decidedly questionable. For example, Hammersley (1999) pointed out that in qualitative research it is very usual to make quantitative statements in a verbal form, using expressions like "regularly," "frequently," "often," "typically," "principally" "primarily," etc. The author states that the form in which such statements are made makes no difference to their substance, which always refers to quantity. In other words, when referring to the presence of a certain element within a series of interviews using words like "never," "sometimes," or "always," one is still quantifying a phenomenon. It is in fact probably incorrect to state that any kind of language or form of presentation of the results is exclusively qualitative or quantitative, since some form of mutual translatability is usually possible, while leaving the semantic dimension substantially unchanged.

Cross-References

► Experimental and Quasi-Experimental Designs for Research on Learning
► Field Experiments
► Methods/Methodology of Learning Research: Overview
► Qualitative Research Methods

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Mixed Reality Learning

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Synonyms

Learning in mixed realities

Definition

Learning in Mixed Realities (*Mixed Reality Learning*) combines *Situated Learning* and *eLearning*. It uses a well-balanced mixture of learning in the physical context and computer-supported learning with contextualized information access. A physical environment and the physical objects contained within the learning environment are tightly connected to digital information and computer-controlled learning procedures. The digitally enriched physical space for the activities is designed as an *Ambient Environment* where embedded, mostly invisible computers provide hardware- and software-based functionality attached to the room and its objects. Objects in the environment are designed as *Tangible Objects* with intertwined physical and digital properties. As a result, the learner encounters a natural learning context enhanced by eLearning functionality. The strength of Situated Learning is combined with the strength of *Computer-Based Instruction*. Successful methods of conventional learning in the physical realm can be reused for Mixed Reality Learning without or with only minor adaptations. Additionally new forms of learning and teaching can be developed.

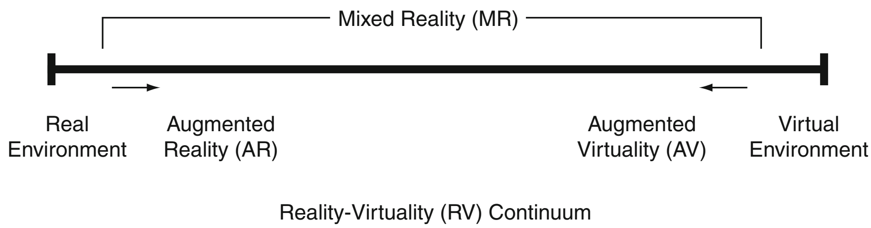
Theoretical Background

Research on Mixed Reality Learning follows several topics and combines them on the conceptual and the technical level:

- Situated learning
- eLearning
- Augmented, mixed, and virtual realities
- Immersion with bodily experiences in virtual environments
- Mobile learning
- Simulator technologies

The theory and the hypotheses about the utility of Mixed Reality Learning are based on the effectiveness of *Situated Learning* opposed to class room learning and similar artificial and decontextualized learning and teaching methods (Winkler et al. 2002; Rogers et al. 2002; Kirkley and Kirkley 2004). Situated Learning takes place at the location where a problem emerges or a task has to be performed. Early work had been done by Maria Montessori through her discussions and experiments about the importance of physical experiences, i.e., *sensual and bodily experiences*, for learning the close relations between learning and the development of children's body and mind were analyzed by Jean Piaget. Seymour Papert translated the theories of Piaget, among others, into learning and teaching applications using interactive computer systems (Papert 1980). Situated Learning requires a tight relation between a learner and the "natural environment" and "natural objects" of the learning domain. "Natural" does not necessarily mean that it happens in nature, it just expresses that the environment and the objects of the problem domain as well as their behavior are defining the learning context. The learner is situated in this "natural context" and performs the problem solving activities.

Computer-Supported Learning (*eLearning*) has a long tradition in pedagogy and computer science. Early work for eLearning has been started in the late 1960s when the first computer-supported learning systems and environments had been designed and some of them, depending on the state of technology, had been implemented. In the further development of eLearning, over several steps to its today widely used form of *Web-Based Training*, the learner has been relocated from the class room to the computer work place. Learning in Mixed Realities tries to reverse this development in the sense that it moves the computer to the locations where learning can take place most effectively and most naturally. The computer will be embedded into the learning environment in a more or less invisible way. This combines eLearning with the development of *Augmented, Mixed, and Virtual Realities* as well as *Ambient and Smart Environments*. Approaches like this have also been discussed as so-called Ubiquitous Computing in

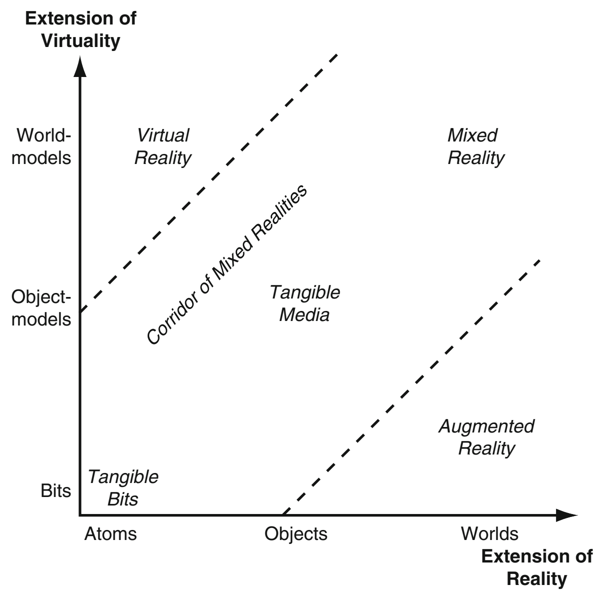


Mixed Reality Learning. Fig. 1 1-dimensional Reality-Virtuality Continuum defining Mixed Realities (Milgram et al. 1994)

the sense of generally available computer systems in our living environments (Weiser 1991).

Augmented, Mixed, and Virtual Realities can be viewed in the spectrum of combining digitally created virtual worlds with the physical reality. Milgram et al. (1994) illustrated it as a one-dimensional spectrum (Fig. 1).

When the physical and the digital components of a world construction are somehow balanced, it will be called *Mixed Reality*. Objects in the realm of Mixed Realities are called *Tangible Objects* or short *Tangibles* (Ishii and Ullmer 1997). The interfaces between humans and tangible objects are called *Tangible User Interfaces* (*TUIs*). They consist of a physical representation, which can be touched, grabbed, and manipulated like ordinary physical objects, and of a digital representation adding virtual properties. Physical and digital properties are connected and related to each other in real-time. Combining the digital and the physical domains can be modeled in a two-dimensional abstract space, conceptualizing a *Corridor of Mixed Reality*, where physical and digital worlds are more or less balanced and provide the advantages of both dimensions (Fig. 2).



Mixed Reality Learning. Fig. 2 2-dimensional Reality-Virtuality Continuum defining a Corridor of Mixed Realities (Herczeg 2006)

Mixed Reality Systems have the potential of creating learning contexts where the learners can interact not only through cognition but through their bodies and their perception as well. They can move and act with their whole bodies in a natural way. The computer systems of the ambient environment will identify them, detect their motions and activities, and provide corresponding information or changed augmentation of the environment and its objects. The computer creates dynamically *Affordances* (Gibson 1977), i.e., opportunities for interaction for the subsequent activities according to the learning process. This corresponds quite well to the learning theories of Montessori and modern followers.

Mixed and Virtual Realities have been described to create the perception of *Immersion*, i.e., being mentally or even bodily engaged and integrated into a virtual environment (Sherman and Craig 2003). This notion of immersion is tightly coupled with the interaction concept of *Direct Manipulation* (Hutchins et al. 1986) and the design concept of *Experience Design* (Shedroff 2001; Herczeg 2004). Users, i.e., learners, can be highly engaged into the interactive environment.

An additional approach of using technology for Mixed Reality Learning is *Mobile Learning*. Instead of embedding computer systems into the environment or into objects, mobile computers like PDAs, eBooks, smart phones, notebooks, wearables, and even implants may be used within the learning contexts. They usually do not blend invisibly into the learning environment, but they are able to provide functionality and information access at the location where situated learning takes place.

This will not have the strength of the close connection of the physical and the digital like in mixed realities, but will be a pragmatic and easy way of implementing or enriching the mixture of digital and physical situations in a finer grained form than working with desktop or even mainframe computers. It has been shown in many projects that mobiles allow for a variety of new or extended contextualized learning scenarios.

Mixed Reality Learning follows the idea of enriching well-known physical learning and teaching environments with digital information and computer functionality. Therefore conventional, already successful learning and teaching methods can be applied, like combining physical and mental tasks and efforts in indoor and outdoor gaming (Scharf et al. 2008). Developments like *Pervasive Gaming* with a seamless integration of such technologies applied to learning contexts are a promising option for future research and application. However, Mixed Reality Learning has a potential of its own providing added values to the plain combination of Situated Learning and eLearning. Some of these values are information at its place where it belongs to logically or where it is needed, even down to the object level (located information), cognitive support for body-oriented learning activities (like in sports), or the usage of a broader perceptual and sensory-motor channel for human–computer interactions.

Important Scientific Research and Open Questions

Mixed Reality Learning is just at the beginning of its development and distribution. For many years the only developed and evaluated solutions which applied the method in its major characteristics have been simulators like being used for transport systems (e.g., flight, ship, or car simulators) or in the industry (e.g., power plant control room simulators) for supervisory control applications.

Only a few prototypes and settings have been built yet according to these principles for schools or similar teaching and learning contexts (Winkler et al. 2002; Rogers et al. 2002; Reimann et al. 2003; Melzer et al. 2005). The main challenges are how to interrelate physical and digital properties, how to identify and interpret human activities by computers, and how to embed the systems in a proper way without interfering disturbingly with the physical environment and the learning activities taking place.

To make use of the full potential of Mixed Reality Learning it is necessary to develop learning and teaching scenarios where mixing the physical and the digital world is of a well-defined added value (Winkler et al. 2009) instead of just implementing technologically possible systems.

The current mainstream of developing new input-output devices to be used as user interfaces to computers already meets many of the essential requirements of Mixed Reality Learning. Systems like multi-touch tables, three-dimensional walls with remote input, augmented reality goggles, gesture input, or tactile input-output with force-feedback are useful components for Mixed Reality Learning Systems. They have to be incorporated into learning systems with well-defined properties and real advantages for teaching and learning.

Cross-References

► Affordances
► Computer-Based Learning
► Computer-based Learning Environments
► e-Learning
► Situated Cognition
► Situated Learning

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Mixed Research on Learning

► Mixed Methods Research on Learning

M-Learning

► Mobile Learning

M-Learning Envrionments

► Mobile Learning

Mnemonic Devices

► Mnemotechnics in Second-Language Learning

Mnemonic Instruction

► Mnemotechnics and Learning

Mnemonic Learning

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Synonyms

Memory aids; Memory-enhancing strategies

Definition

In Greek mythology, Mnemosyne was a Titaness and mother (by Zeus) of the nine Muses. She was also the personification of memory. A "mnemonic" then, is any procedure or operation designed to improve memory and/or remember something. Although, very broadly, this term could refer to very simple strategies, such as rehearsal, the particular mnemonic strategies described here are those that involve a transformation of target content into more familiar forms, and a provision of explicit retrieval routes between stimuli and to-be-learned information. There are several different types of these transformational mnemonic strategies, including the keyword method, the pegword method, and letter strategies.

The keyword method works by transforming unfamiliar information into concrete, similar-sounding proxies (the keyword), and then associating the keyword with information to be learned and remembered, in a picture or image that shows the two elements interacting. For example, in order to remember that the word *pato* means "duck" in Spanish, a keyword is first constructed for "pato." In this case, a good keyword would be "pot," because it sounds like pato and is easily pictured. Learners are then shown (or asked to imagine) a picture of the keyword and associated information interacting, in this case, in a picture of a duck with a pot on its head. When asked for the meaning of pato, then, learners first think of the keyword, *pot*, think of the picture with the pot in it, remember *what else* was in the picture (a duck), and retrieve the answer, "duck."

The pegword method works similarly for content that includes numbered or ordered information. In this case, numbers are transformed into rhyming pegwords (one is *bun*, two is *shoe*, etc.) and associated with the to-be-remembered information. For example, to remember that a rake is an example of a *third-class* lever, an interactive picture can be created of a rake leaning against a *tree* (pegword for three, or third). Learners retrieve the image of the rake, remember it leaning on a tree, and retrieve the answer, three, or third-class lever.

Letter strategies are probably the most familiar of the mnemonic strategies. They employ letters in words or sentences to retrieve lists of information. Most people are familiar with HOMES, the acronym for the names of the Great Lakes: Huron, Ontario, Michigan, and so on. All these types of mnemonic strategy work by transforming unfamiliar information into more meaningful forms, and associating them with information already in the learner's memory.

Theoretical Background

Effective recall of associative information (very commonly found in many school curricula) is dependent upon establishing efficient pathways between the stimulus and the response; these efficient pathways in turn require efficient *response learning* and *associative learning* sub-processes (Underwood and Schultz 1960). Response learning requires that learners become familiar with the separate to-be-associated elements, while the associative sub-process requires that they acquire specific connections between stimulus and response. Therefore, any method that serves to enhance the familiarity or meaningfulness of the stimuli, in addition to any method that strengthens the association between the elements would be expected to improve learning and memory.

With specific reference to the keyword method, the creation of the keyword serves to enhance familiarity, by transforming unfamiliar information (e.g., "pato") into more meaningful entities ("pot"). Since it is known that meaningful stimuli are learned more rapidly than non-meaningful ones (e.g., Paivio 1971), this type of transformation would be expected to be helpful. In addition, the interactive element of a mnemonic picture (for example, a duck with a pot on its head) serves to integrate the formerly unrelated elements into a meaningful whole. Since it is known that thematically elaborated stimuli are better remembered than unelaborated ones, the shared semantic relationship represented in an interactive picture or image would be expected to improve memory. Since the keyword method and related mnemonic learning strategies provide explicit retrieval instructions, invoking stimulus enhancement and strengthening associative connections, enhanced retrieval would be expected, and in fact has frequently been demonstrated (Mastropieri et al. 1985).

Important Scientific Research and Open Questions

Although mnemonic techniques were employed at least as long ago as the time of the ancient Greeks, the first modern scientific study was conducted by Atkinson (1975), involving the utility of the keyword method to teach Russian vocabulary to college undergraduates. Since that time, the keyword method and related techniques have been applied to increase substantially the learning and memory of normally achieving learners of a number of age levels, and in a variety of content domains (Pressley et al. 1982). More recently, mnemonic techniques have been employed successfully with students with mild disabilities (learning disabilities, intellectual disabilities, emotional/behavioral disabilities) in a number of subject areas, including English and second-language learning, social studies (including state, national, and world history), and science (including geology, earth history, biology, and chemistry). Scruggs and Mastropieri (2000) summarized research findings from 34 relevant experiments involving mnemonic techniques, and reported mean effect size of 1.62 (*SD* =.84), indicating very substantial improvements in learning and memory over a variety of comparison conditions. To date, mnemonic strategies have been successfully applied in the elementary, middle-school, and high-school levels, with normally achieving learners, learners with mild disabilities, and intellectually "gifted" students, with a high degree of success in each case. Although the effectiveness of mnemonic learning techniques has been amply demonstrated, more research remains to be conducted on techniques for developing the propensity of learners to apply these strategies in their own learning, spontaneously and generally, across extended time periods.

Cross-References

- ▶ Associative Learning
- ▶ Cognitive Learning
- ▶ Cognitive Tasks and Learning
- ▶ Learning and Thinking
- ▶ Mental Imagery and Learning
- ▶ Mnemotechnics and Learning
- ▶ Paired-Associate Learning

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Mnemonics

- ▶ Learning by Chunking
- ▶ Mnemotechnics in Second-Language Learning

Mnemotechnics and Learning

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Synonyms

Memory aides; Memory-enhancing strategies; Mnemonic instruction

Definition

"Mnemotechnics" refers to the application of mnemonic principles and techniques in order to organize memory impressions and facilitate later recall. Mnemonic learning refers to the use of mnemonic strategies employed during instruction and/or the learning process to facilitate learning (see Mnemonic Learning entry for additional information). The purpose is to make learning more memorable. Mnemonic techniques involve a broad class of strategies from simple to complex in nature, such as rehearsal, clustering, organizational, and transformation including the keyword, pegword, and letter strategies. The formats of mnemonic strategies range from verbal (e.g., simply restating for rehearsal), imagery (e.g., creating a mental picture of the to-be-remembered information), to concrete (e.g., drawing or looking at a picture of the strategy containing the to-be-recalled content). Strategies can also be taught to learners, who can then develop their own idiosyncratic mnemonic strategies. Procedures for developing these strategies can also be presented to students during instruction. The use of the more complex strategies may require extra instruction and practice with students that have disabilities or learners who are less sophisticated. The keyword mnemonic strategy transforms an unfamiliar word, name, or term into an acoustically similar and concrete proxy which then interacts with the to-be-associated information in an interactive picture, verbal statement, or image. The keyword method has been used successfully with students of all ages, but most effectively with students with learning difficulties, including learning disabilities, mild cognitive disabilities, and emotional/behavioral disabilities.

Researchers have developed mnemonic strategies to accompany large units of instruction in science and social studies. For example, using combinations of the keyword, pegword, and first letter strategies, the content from World War I (WWI) through World War II was successfully taught to secondary-level students with learning disabilities (Mastropieri and Scruggs 1988). In these studies teachers identified content that was difficult to remember and used mnemonic illustrations in order to teach it. For example, students were taught that countries in the Allied Powers during WWI were France, Italy, Russia, and England through an interactive illustration using the keyword method combined with a first letter strategy such that an Allied

Van was the keyword for ALLIED Powers and a FIRE in the van was a first letter strategy for the name of each country in the Allied Powers. When asked what were the countries in the Allied Powers, students were taught to think of the keyword "Allied van" and then what was happening in the picture with the Allied van on FIRE in which F represented France; I, Italy; R, Russia; and E, England. Since important individuals are initially unfamiliar and difficult to remember, these major figures were taught mnemonically. For example, to teach that George M. Cohan wrote the famous song Over There, students were taught the keyword "cone" (as in ice cream cone) for Cohan, and then shown an interactive illustration of someone asking where children got that cone, and depicting students singing "Over There, Over There" as they pointed to an ice cream cone stand. When asked what George M. Cohan was famous for, students were reminded to think of the keyword "cone," what was happening in the picture with the "cone" in it, and then retrieve the response Cohan wrote the patriotic song, "Over There."

Scruggs and Mastropieri (1992) later applied the same model to science learning and developed several units of instruction designed to teach difficult-to-learn content using mnemonic strategies. More recently, mnemonic strategies have been embedded within materials designed to be used in peer tutoring in inclusive classes, containing students with and without disabilities (Mastropieri et al. 2005). With these materials only students who needed the strategy used it and other students skipped it. For example, important content in chemistry was identified and mnemonic strategies were developed for difficult-to-learn content. The materials that were developed included a mnemonic illustration to facilitate learning of the concept of a mole (as the atomic weight in grams) using a picture of a mole (the animal) on a weighing scale with the statement "weight in grams." If students already knew that piece of information they were directed to the next questions: What else is important about moles? What is an example of a mole? Marshak et al. (2011) successfully applied this model of peer-mediated embedded mnemonic instruction to inclusive middle school social studies classes. In both of these studies, students with and without disabilities recalled more information than students in a non-mnemonic comparison condition.

Theoretical Background

Effective recall of associative information depends upon establishing efficient pathways between stimulus and response, which requires enhancing the familiarity of stimulus information and the relationship between stimulus and response (Paivio 1971; Underwood and Schultz 1960). Mnemotechnics accomplishes this by replacing an unfamiliar stimulus with a familiar, acoustically similar proxy, the keyword, and relating the keyword to the response through an interactive illustration or image (see Mnemonic Learning entry for a discussion).

Important Scientific Research and Open Questions

Although mnemonic techniques have been used for centuries, Atkinson (1975) documented the first effective use of the keyword strategy to teach foreign-language vocabulary to college students. Subsequently, numerous studies documented the efficacy of the approach across a variety of age levels (Pressley et al. 1982). Later, applications of the keyword method were applied with students with mild cognitive and intellectual disabilities, who consistently outperformed comparison students in a variety of subject areas (Scruggs and Mastropieri 2000). More recently, mnemonic strategies have been embedded within materials designed for classwide peer tutoring in classes of students with diverse learning needs (Marshak et al. 2011). Although mnemotechnics have been seen to be very effective in virtually all experimental investigations to date, effects of very broad applications (e.g., over several years) of provided or learner-generated mnemonics have yet to be studied.

Cross-References

- ► Associative Learning
- ► Cognitive Learning
- ► Cognitive Tasks and Learning
- ► Learning and Thinking
- ► Mental Imagery and Learning
- ► Mnemonic Learning
- ► Paired-Associate Learning

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Mnemotechnics in Second-Language Learning

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Synonyms

Mnemonics; Mnemonic devices

Definition

The term *mnemotechnics* (from the Greek word μνήμων "mnēmōn," mindful) refers to a group of mnemonic devices, that is, tools and techniques which aid memorization. These techniques commonly rely on associations relating the items to be remembered to other entities, thus making them easier to store and recall (see also ► Mnemotechnics and Learning).

With regard to second-language learning, various mnemotechnics are employed as ► second-language learning strategies to enable learners to remember and retrieve language items. Some of these strategies involve *creating mental links* between language items, like categorizing words into meaningful units (e.g., learning a random list by grouping the elements according to word class, topic, etc.), while others involve *applying images* (e.g., the method of loci: using a set of locations for remembering a sequence of words) and/or *sounds* (e.g., using rhymes to remember difficult spellings, like the phrase "I before E except after C"). Alternatively, some mnemonic devices assist recall via *employing action* (e.g., using physical response: physically acting out a new expression like "opening the window," or applying mechanical techniques like using file cards). Moreover, mnemotechnics in second-language learning can be used specifically to remember items in a *systematic order* (e.g., by using acronyms: the acronym "bangs," for instance, can help English-speaking learners of French to remember the order of adjectives before the noun, "Beauty, Age, Number, Goodness, and Size"; for a detailed listing of mnemonics and examples see Oxford (1990, pp. 38–43).

Frequently, mnemonic devices applied in second-language learning involve a combination of different sensory modalities, for example, verbal and visual input, which serves the purpose of making the information to be learned more prominent and also complies with learners' different ► sensory learning style preferences. A method which is particularly popular in this context is the *keyword method*, which is used in vocabulary learning for remembering word meanings and involves a combination of an acoustic link and an imagery link between a native language (L1) word or phrase and a second-language (L2) word. First, an L1 word (the keyword) is chosen on the basis of acoustic and/or orthographic similarity with the L2 word to be acquired. Then, the learner forms a strong association between the target word and the keyword, so that he/she is immediately reminded of the keyword when encountering the target word. Thirdly, a visual image is constructed which combines the keyword and the target word, preferably in a salient manner in order to make memorization easier. For example, an English learner of German intending to learn the word *Raupe* (caterpillar) could associate *Raupe* with the English word *rope* (sound similarity) and construct a mental image representing a caterpillar on a rope, perhaps in some exaggerated manner to make it more salient (Hulstijn 1997). As an alternative to the combination of verbal and visual association, the keyword method can also be employed in a purely verbal version: here, instead of creating an interactive image in the third step, a learner would create a meaningful sentence in his/her L1 that connects the keyword and the target word, for example, to remember the French word *soupape* (valve) using the English keyword *soup*, the verbal mediator phrase *to soup up the engine* could be used (Hulstijn 1997).

Theoretical Background

Mnemotechnics have been popular aids for memorization for thousands of years and have been investigated by philosophers and psychologists since ancient times. As regards applying this technique to second-language learning, research is based on the assumption that mnemonic devices provide powerful memorization aids and can thus support specifically those language-learning tasks which are predominantly related to memory. Consequently, pertinent research has concentrated on the area of ► vocabulary learning, which involves memorizing large numbers of words. The one mnemonic method investigated most extensively in this context is the *keyword method*; research in this area was stimulated by the work of Atkinson and Raugh, who carried out a range of studies investigating mnemonic aids for vocabulary learning, and as a result invented the keyword method and coined the term (Atkinson 1975).

As regards contemporary research in this field, most investigations compare one type of mnemonic device, in most cases the keyword method, with a range of other learning techniques like ► rote memorization, using pictures, or guessing from context, and mainly claim that the keyword method is superior to most other methods tested, concluding that learners generally benefit from applying this strategy. More specifically, some researchers have argued that the ► depth of processing also plays a role, finding that the most promising results were achieved if the keyword method (involving shallow semantic processing) was combined with a semantic strategy involving deeper levels of processing. While the usual method involves learners creating the keywords themselves, the keyword technique can be also applied with preselected keywords, which appears to work equally well for younger learners. To ensure that learners are able to make use of the keyword method effectively, however, it has also been stressed that extended skill training is required – for a detailed review, see Hulstijn (1997) or Nation (2001).

Important Scientific Research and Open Questions

In contrast to the favorable results reached in most studies investigating mnemotechnics in second-language vocabulary learning, some questions concerning their effectiveness remain open (Cohen 1987; Nation 2001):

- Mnemonic devices mainly aim at the retention of language items. It is not quite clear yet how well learners can actually use mnemonics for L2 production, specifically under the time constraints of oral conversation.
- Mnemonics may not be equally suitable for all learners. In fact, selected research results suggest that the keyword method may be more successful with specific groups of students, for example, beginners needing to memorize a large number of words.
- Findings on the effect of mnemonics on retention are not consistent. While mnemonics can certainly improve immediate recall, some studies show that they appear to fall behind other strategies for long-term retention.

Furthermore, it has also been pointed out that mnemonic devices should be applied with caution for the following reasons:

- Only some types of word are in fact suitable for mnemonic devices (e.g., the keyword technique can only be successfully applied with words referring to visual objects), while other types do not seem to lend themselves equally well to applying these strategies.
- The mnemonic approach tends to focus on learning vocabulary from lists, advocating a one-to-one relationship between form and meaning which does not correspond to the various dimensions of word meaning. In addition, too much focus on learning vocabulary as discrete items may lead to neglecting contextual aspects.

All in all, however, researchers seem to underline the relevance of mnemotechnics for second-language learning provided that they are used to complement other techniques, rather than to replace them, and that teachers and learners are aware of the limitations of these methods.

As regards the actual use of mnemotechnics in language teaching practice, it appears that unlike the recommendations of most researchers, the keyword method seems to be only rarely used in actual second-language instruction, and only marginally (if at all) mentioned in most language teaching books (Hulstijn 1997). Selected language teaching materials can be found, however, which emphasize the use of the keyword method and related mnemonics.

Cross-References

- ▶ Learning Strategies
- ▶ Learning Style(s)
- ▶ Mnemonic Learning
- ▶ Mnemotechnics and Learning
- ▶ Rote Memorization
- ▶ Vocabulary Learning in a Second Language

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Mobile CSCL

▶ Learning with Collaborative Mobile Technologies

Mobile Learning

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Synonyms

eLearning; M-Learning; M-Learning environments

Definition

PDA: Personal Digital Assistant is a handheld device with communicative and computational capabilities. It can function as a personal organizer, web browser, fax sender, and cellular phone.

e-Learning: It refers to the delivery of a learning, training, or education program by electronic means.

Information and Communication Technologies (ICT): It refers to any product that is concerned with the storage, retrieval, manipulation, transmission, or receipt of digital data. It is also concerned with the way these different uses can work with each other.

Mobile learning: It refers to the use of mobile devices, such as PDAs or cellular phones in learning activities anywhere and anytime, bringing information and knowledge to situations and places where learning activities take place.

Theoretical Background

Mobile phones are now used in almost every region of the world, and with countries often having five to ten times more mobile phones than personal computers (PCs), these devices are very attractive options to incorporate the new Information and Communication Technologies (ICTs) into education. Mobile phones are more personal devices than PCs; they are user-centered, almost always are connected (connectivity), and nearly always are with us (portability). These characteristics make them very appropriate to support truly anywhere and anytime learning activities.

For many researchers and educators, mobile learning is the new step in e-learning evolution. Caudill (2007), quoting several authors, presents some definitions for mobile learning: "The point at which mobile computing and e-Learning intersect to produce an anytime, anywhere learning experience.", "A mobile learning educational process can be considered as any learning and teaching activity that is possible through mobile tools or in settings where mobile equipment is available.", ". . .e-learning that uses mobile devices and wireless transmission." All these definitions are device-based and therefore, technology-bounded. Some researches have proposed more holistic definitions, for example, Laouris and Eteokleous(2006) proposed that definition of mobile learning must take into account not only technical, methodological, and educational aspects, but also consider social and philosophical dimensions, because mobile learning requires a new philosophical framework and new educational paradigms if it is to thrive. Sharples et al. (2005) define mobile learning as a changing process of "coming to know" through conversation in context, in cooperation with peers and teachers to construct interpretations of the world. This process is supported by knowledge and technology as instruments for productive inquiry. In mobile learning environments, the mobile devices should play the role of mediator between the learners, support their interaction, and provide information and knowledge resources just in time and just in place. For Ayala et al. (2010), mobile learning refers to the use of mobile technologies to support learning activities anywhere, anytime and just in place.

In order to be effective, the development of innovative learning environments requires to be based on sound learning theories. Mobile learning is supported by the following learning theories and techniques: situated learning, personalized learning, collaborative learning, ubiquitous learning, and lifelong learning (Sharples et al. 2005). Parsons and Ryu (2006) identified some requirements for quality mobile learning: it should be based on sound pedagogical principles which take into account the learner type, needs and context; contents must be updated; it should be interactive; it must allow dialogs between teachers and learners; it must help in the identification of knowledge gaps; it should enable the learner to construct and explore knowledge; it should allow learners to communicate and collaborate with peers; and it should enable the learners to control their own learning. Because of its characteristics, mobile learning seems to be specially suited for informal and lifelong learning.

Even when is relatively new, it is a very fast growing research area. In June 2005, Laouris and Eteokleous (2006) ran a Google search for "'mobile learning' + definition," and received 1,240 items. In December 2009, we ran the same search in Google and received 39,900 items.

Given the vast diversity of characteristics of mobile devices, even between devices from the same manufacturer, the diversity of wireless networking technologies, and its novelty, adoption of mobile learning faces several obstacles. One of them is the lack of technical standards. Adoption of HTML 5 promises to alleviate in some degree this problem. It is also important to look at how people actually use mobile devices in order to develop learning applications which take advantage of these already adopted methods. Example of this is the use of SMS (Short Messages Service) to deliver administrative information and learning content to students. The lack of friendly and ease-of-use tools to develop learning contents for mobile technologies is another impeding factor for mobile learning adoption. It also necessary to adopt appropriate business models to assure mobile learning delivery (Ganci 2010). Nowadays, mobile learning is mostly based on research projects, focused on the exploration of theoretical and methodological foundations for the creation of contents for mobile technologies. We are still waiting for the "killer application" that makes mobile learning be massively adopted.

Important Scientific Research and Open Questions

Between the current research interests in the area of Mobile Learning, we can mention the following topics:

1. Design, use, and delivery of learning objects for mobile learning environments. The learning object concept includes two main characteristics: a digital content that allows or facilitates to achieve an educational objective, and reusability. Proper combination of these features of learning objects with personalization, connectivity, and ubiquity of mobile technologies is an open question. Nowadays there is interest to extend the learning object concept to mobile learning contexts, in such a way that the user can interact with this knowledge elements using mobile devices. There are emerging design guidelines and computational models for this mLearning Objects (Katz and Worsham 2005). Quinn has introduced the concept of flexible learning object (2004) for mobile devices, proposing three levels at which learning objects for mobile devices can be developed: a library of material that learners can choose from, data to categorize courses and optimize the offerings; and the experience, knowledge, and individual differences and needs of users. There had been also proposals to adapt the standard SCORM 2004 in order to be used in mobile learning environments (Ayala et al. 2010; Chan et al. 2004).
2. Design and implementation of learning activities using mobile technologies designed to support

innovative educational practice is another open question. The use of mobile phones can promote the shift from instructor centered teaching in a classroom to a constructivist educative environment centered on the learner and just in place, out of classrooms, like museums for history subjects, or in the field for biology subjects (Holzinger et al. 2005).

3. The role of Mobile Learning in developing countries is another open research question. International community is motivated with the possibility that wireless technologies contribute to overcome the digital divide in education in the developed and developing world (Smyth 2006).

Cross-References

► Cognitive Learning Strategies for Digital Media
► eLearning and Digital Learning
► Learning Technology
► Learning Through Social Media

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Modality Effect on Learning

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Synonyms

Modality principle

Definition

The *modality effect* refers to a cognitive load learning effect which occurs when a mixed mode (partly visual and partly auditory) presentation of information is more effective than when the same information is presented in a single mode (either visual or auditory alone). Take, for example, a geometry problem consisting of a diagram and its associated statements. Although the diagram must be presented visually, the associated statements can be presented either visually or orally. From a cognitive load theory perspective, the conventional picture with written text presentation format imposes a high load in the visual working memory system since both sources of information are processed in the same system. In contrast, the diagram and narration version induces a lower load in the visual working memory because auditory and visual information are each processed in their respective systems. The modality effect occurs because the total load induced by this format is spread between the visual and the auditory components in the working memory system.

Theoretical Background

Cognitive and educational psychologists have been exploring the modality effect for many years. Low and Sweller (2005) provide a discussion of the research demonstrating this effect. Mayer (2001) uses the term "modality principle" to describe the effect, and Penney's (1989) extensive literature review refers to it as "separate streams hypothesis." Evidence for the modality effect unambiguously established that performance can be enhanced by using dual-mode presentation techniques. This modality effect is closely associated with Paivio's dual-coding theory (Clark and Paivio 1991; Paivio 1986) and Baddeley's model of working memory (Baddeley 1986, 1999). It is explainable by cognitive load theory, an instructional theory based on our knowledge of human cognitive architecture that specifically addresses the limitations of working memory.

Cognitive load theory assumes that most cognitive activities are driven by a large store of information held in long-term memory. This knowledge directs the manner in which information is processed in working memory. For learning to occur, novel material must be organized and incorporated into long-term memory via a limited working memory. For instruction to be effective, it has to be designed in ways in which the limitations of the working memory are overcome (see Low et al. 2011, for a more detailed discussion on working memory characteristics and instructional implications). According to cognitive load theory, many instructional materials and techniques may be ineffective because they ignore the limitations of human working memory and impose a heavy extraneous cognitive load.

Cognitive load theory distinguishes between three kinds of cognitive load: intrinsic, germane, and extraneous load. Intrinsic cognitive load is related to task difficulty and is due to the complexity of the information that must be processed. Germane load (Paas and van Merriënboer 1994) is the cognitive load caused by effortful learning due to attentional (working memory) resources being directed to intrinsic cognitive load. Extraneous cognitive load is caused by instructional designs that do not take into consideration the limitation of working memory resources that are necessary for learning. Extraneous load can be manipulated in two ways: formatting instructional material in a manner that minimizes cognitive activities that are not necessary to learning so that cognitive resources can be freed to concentrate on activities essential to learning, and expanding effective working memory capacity. The modality effect falls into the latter category whereby learning is facilitated because of the use of dual modality instructional materials. In other words, the combination of visual and audio information may not overload working memory if its capacity is effectively expanded via a dual mode presentation.

Important Scientific Research and Open Questions

Mousavi et al. (1995) tested this hypothesis in educational settings via a series of experiments using geometry problems. There were two presentation conditions: visual-visual and audio-visual. In the visual-visual presentation, both diagrams and associated texts were given in a visual format as presented conventionally in textbooks, whereas in the audio-visual presentation, while diagrams were given visually, their related texts were provided as audio input. Results indicated that learners in the audio-visual group performed much better than did those in the visual-visual group. Audio-visual instructions were consistently superior to visual-visual instructions demonstrating the modality effect. This basic modality effect was replicated in subsequent experimental studies employing different learning materials. Tindall-Ford et al. (1997) reported increased effective working memory and improved learning outcomes under audio-visual conditions in comparison with visual-visual conditions in electrical engineering courses. Jeung et al. (1997) reported improved learning outcomes by using visual indicators to highlight the most complex parts of information in spoken texts. Kalyuga et al. (2000) reported an enhanced learning experience by beginners from dual-mode presentations in an industrial training course.

The modality effect has also been demonstrated by experimental work undertaken by Mayer and his colleagues on multimedia learning (Mayer and Moreno 1998; Moreno and Mayer 1999; Moreno et al. 2001) using web-based or computer-aided instructional design. Brünken et al. (2002) replicated the modality effect using a dual-task approach. They found that the differences in learning outcome demonstrated by the modality effect were related to different levels of cognitive load induced by the different presentation formats of the learning material. Specifically, they found that an emphasis on visual presentation of material resulted in a decrement on a visual secondary task, indicating an overload of the visual processor. In a subsequent study, Brünken et al. (2004) again reproduced the modality effect when the secondary task was auditory instead of visual, and there was a decrement in performance on the auditory secondary task when the primary task placed an emphasis on the auditory processor.

While the modality effect is robust and has been demonstrated in a variety of conditions, there have also been exceptions. Tabbers et al. (2004) obtained a reverse modality effect where visual-only instructions were found to be superior to audio-visual instructions under self-paced conditions. Wouters et al. (2009) did not obtain a modality effect under self-paced conditions while Schmidt-Weigand et al. (2009) did not obtain an overall modality effect under system or self-paced conditions. These findings are explicable by cognitive load theory. The three studies used complex and/or lengthy audio/written materials. It is possible that under conditions where auditory and visual text materials are complex and/or lengthy, working memory may be overloaded thus eliminating any effects.

The modality effect depends heavily on the logical relation between the various sources of information. The effect is only obtainable when the various sources of information are unintelligible in isolation and must be mentally integrated before they can be understood. Thus, a diagram and text such as a geometry diagram and an explanation can be used to demonstrate the modality effect because a statement such as Angle XYZ is unintelligible without reference to a diagram. In contrast, if diagrams or text are intelligible in their own right and simply redescribe each other, physical integration or the use of dual-modality presentations will not be beneficial. Under such conditions, elimination of redundancy is necessary.

The modality effect has both theoretical and practical implications. Theoretically, it provides additional evidence that effective working memory capacity may be increased, and this increase can facilitate learning. From a practical perspective, the modality effect provides guidelines for effective instruction. It is especially important in the context of multimedia instruction as the medium involves various presentation modes and different sensory modalities.

Cross-References

► Cognitive Load Measurement
► Cognitive Load Theory
► Design of Learning Environments
► Human Cognitive Architecture
► Redundancy Effect

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Modality Principle

► Modality Effect on Learning

Model

► Scaffolding Learning by the Use of Visual Representations

Model Eliciting Activities

► Mathematical Models/Modeling in Math Learning

Model-Based Imitation Learning

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Synonyms

Behavioral cloning; Learning from demonstration; Machine learning; Robotics; Skill transfer

Definition

Model-based imitation refers to a family of machine-learning methods, which can be used to quickly generate a rough solution to a given control task, usually in robotics, using demonstrated behavior. The premise is that a large class of tasks can be demonstrated, either by a human, e.g., household tasks for domestic robots, or by other "teacher" robots that are more skilled than the learner. The solution, as observed by the learner, typically consists of trajectories in the space of some observed variables. The appropriate actions that are needed to steer the robot along the trajectories usually cannot be observed, but they can be learnt by using a model of the robot's dynamics. This gives rise to the term model-based imitation.

Theoretical Background

It has long been known that humans and animals use imitation as a mechanism for acquiring knowledge. Consequently, algorithms and models have been proposed to implement imitation as a learning mechanism in robotics. In a broad class of robotics problems, imitation represents a powerful way for transferring important skills, tasks, and information to a robot. In such a way, a robot can take advantage of the same sorts of learning and teaching scenarios that humans use.

Using data sequences recorded in a demonstration of a specific control task to design a robot controller is called "imitation" or "behavioral cloning." It has been most commonly applied in order to achieve a desired motion pattern. In the literature, this approach is also referred to as "learning from demonstration," "programming by demonstration," "learning by watching," "imitation learning," "expert imitation," and "teaching by showing."

A robot with the ability to imitate the actions of a human provides a simple and effective means for the human to specify a task to the robot without any programming. Such a robot potentially has a considerably lower cost of deployment than the one, which requires programming by an expert. In addition, robots equipped with imitation skills can serve as a testbed for cognitive researchers and provide agents for interaction with humans in psychological experiments. From a machine-learning perspective, imitation is a way to quickly generate a rough solution to a task using demonstrated behavior. It therefore provides a means to constrain the search space and so to speed up the learning process. Imitation can direct the learner to first explore the promising part of the search space, which contains the goal states. This is important when the search space is large and global search is infeasible.

It is important to recognize that learning by imitation refers to an attempt to achieve the goal performed by the teacher. Due to uncertainty in the world and in the robot itself, the goal typically cannot be realized by merely replicating the teachers' actions. It is often the case that the robot and the teacher have the same state and action spaces, but nevertheless the robot does not have the exact same capabilities as the teacher. This is mainly due to limitations in the robot actuators making the robot unable to exactly reproduce the human motion (Atkeson and Schaal 1997). In addition, the actions that are needed to steer the robot during the task often cannot be observed (unless the teacher operates the robot through a joystick or another similar device). Instead, the learner observes the effect of these actions in terms of trajectories in the space of some measured variables, such as positions, joint angles, etc. The appropriate action must be learnt by using a model of the robot's dynamics. This gives rise to the term model-based imitation. In such a case, an inverse dynamic model of the robot can be used to map desired states to actions.

Among the approaches published in the literature, a main distinction can be made between explicit imitation and model-based imitation. Explicit imitation (also called task-level learning or direct-policy learning) uses state-action sequences recorded from the teacher to directly learn the policy by using supervised learning. Model-based imitation (indirect control) needs a model of the process to compute the control policy that allows the robot to follow the demonstrated trajectory.

It has been observed that imitation alone seldom leads to a satisfactory solution. The induced controller is typically not robust with respect to small changes in the control task and should be combined with other, self-learning algorithms such as reinforcement learning (RL). In RL, a reward signal is used to optimize the agent's behavior, rather than relying on examples provided by a teacher. Imitation learning then becomes a two-stage process – the first stage is the copying of the teacher's behavior and the second stage is self-improvement (Peters 2003).

Important Scientific Research and Open Questions

Learning setting: To make the problem tractable, researchers have vastly simplified one or more aspects of the environment and the behaviors of the teacher and the learner. Typically, robots have been trained to perform a single task by observing a human demonstrator. Only simple perceptions are used, which are matched to relevant aspects of the task. For instance, Schaal (1997) used a robot arm with vision to learn a pendulum balancing task performed by a human demonstrator equipped with and markers on the joints. Kuniyoshi et al. (1994) consider a robot learning to replicate a block-stacking task in a constrained environment containing white objects on a black background.

However, in real-world situations, the teacher can be indifferent to the attempts of the learner to imitate it. In such a case, learning is a difficult problem that requires the observer to decide what to imitate, when to imitate, and how to decide whether the imitation is successful.

Representation of control policies: Typically, the trajectories first have to be transformed to a parametric model before they can be used as a control policy. Well-established supervised algorithms and approximators are usually employed, such as neural networks, local linear regression, etc. However, alternatives exist that so far have not been explored that much. Bratko and Šuc (2002) argue that qualitative representations are more flexible and potentially more successful than controllers that simply map states to actions. Examples of qualitative representations are a set of if-then statements relating input to output, the sign of a variable, variable crossing a landmark, variable reaching local extreme, etc.

Cross-References

- ► Imitation Learning from Demonstration
- ► Imitational Learning (of Robots)
- ► Model-Faciliated Learning
- ► Robot Learning from Demonstration

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Model-Based Instruction

▶ Mental Models in Improving Learning

Model-Based Learning

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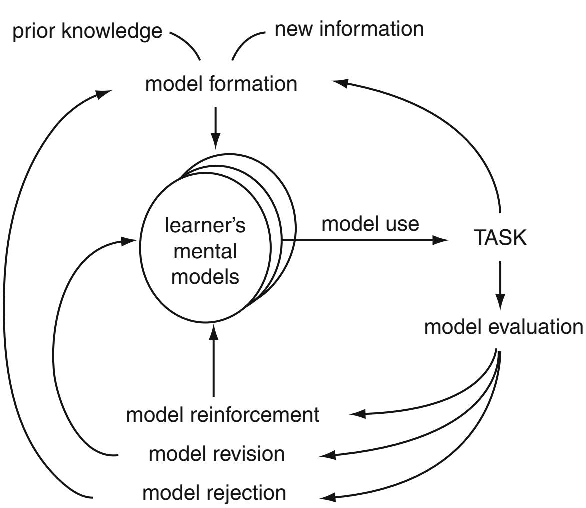
Synonyms

Knowledge integration; Model-building

Definition

Model-based learning is the formation and subsequent development of mental models by a learner. Most often used in the context of dynamic phenomena, mental models organize information about how the components of systems interact to produce the dynamic phenomena. Mental models arise from the demands of some task that requires integration of multiple aspects and/or multiple levels of a system or situation (See Fig. 1). Model formation integrates prior knowledge and new information about the instance into a mental model of the situation. When the mental model is used to accomplish the task, it is evaluated for its utility in performing the task. If the mental model is deemed useful, it is reinforced and may become routinized with repeated use. If the mental model is deemed inadequate, it may be rejected and another model formed, or it may be revised and then used to try again. Revisions may involve making changes to an element of the model or it may take the form of elaboration – adding elements to the model in order to better accomplish the task. Elements may also be dynamic systems. Ideally, model-based learning results in rich, multilevel, interconnected mental models that are extensible and useful for understanding the world.



Model-Based Learning. Fig. 1 Model-based learning

Theoretical Background

Following in the footsteps of Craik (1943), Johnson-Laird (1983) characterized mental models as internal representations of "objects, states of affairs, sequences of events, the way the world is and the social and psychological actions of daily life." They enable reasoning that supports making predictions and generating questions, hypotheses, and explanations. They structure one's understanding of the world by organizing the components of a phenomenon and the interactions of the components that produce some emergent behavior, property, or result. This makes mental models very useful for integrating and extending one's understanding of complex phenomena in a wide variety of settings and domains.

Model-based learning begins with a task, whether explicit or tacit. That task is likely to be trying to understand or produce some phenomenon or representation thereof. The external representations (representations include text as well as diagrams, animations, gestures, physical or computer models; in short, any external representation that stands for something else) are generated from an individual or group's mental models. They may be categorized as either expressed or consensus models. Expressed models are representations of various types generated for a particular purpose. Consensus models, on the other hand, are models developed, agreed upon, and used by a group with some degree of permanence, such as the students in a class or the scientists and scholars of a domain (Gilbert and Boulter 2000).

The contributors to Gentner and Stevens' *Mental Models* (1983) provide an informative array of work on mental models and their use in understanding dynamic phenomena. The chapters range across domains, from electricity to Micronesian navigation to artificial devices. Most of the contributors think about knowledge representation and processing in terms of computational semantics. They employ a very wide collection of methodologies that include protocol analysis, cognitive psychology experiments, developmental studies, novice-expert studies, and multiple settings for observations and comparisons and more. In an attempt to contribute to a theory of how people understand the world, the researchers write primarily about knowledge representations in a domain and phenomenological theories of human processing. Norman (p. 7) makes useful distinctions among models that make it clear that the authors are all writing about their own mental and computational models of learners' mental models and their use in qualitative reasoning. Williams, Hollan, and Stevens (p. 131) define mental models as a collection of connected autonomous objects. "An autonomous object is a mental object with an explicit representation of state, an explicit representation of its topological connections to other objects, and a set of internal parameters. Associated with each... is a set of rules which modify its parameters and thus specify its behaviors (p. 133)." They used protocol analysis to examine one subject's formation and revision of a model of a heat exchanger, facilitated by a "dialectic between the developing mental model and experiential knowledge, (p. 152)." This is an example of model evaluation and revision. deKleer and Brown (p. 155) delve into the assumptions and ambiguities in mechanistic mental models. They distinguish among *device topology* (structure), *envisioning*, a *causal model*, and *running*. *Envisioning* is the process of reasoning from the device's structure to its functioning using known principles (model formation). A *causal model* describes how the structural components interact to produce the behavior or functioning of the device. *Running* the causal model allows one to predict or produce a behavior (model use). deKleer and Brown also discuss embedded models, that is, models whose components are themselves models to describe the depth of knowledge about a device. Using historical protocol analysis, Wiser and Carey (p. 267) describe the formation and revision of consensus models of heat and temperature and their differentiation. Clement (p. 325) highlights the similarities between students' naïve mental models and Galileo's expressed models.

Building on this work, Buckley (2000) used a combination of naturalistic observation and cognitive psychology techniques to examine the understanding of a student using an interactive multimedia resource to learn about the circulatory system. Her analysis identified components of deKleer and Brown's theory at work in a classroom context. In contrast to even the most able students in the class, this student's intentional model-building was evident in researching and planning a presentation for the class and in explaining how a new surgical technique would work when given a newspaper illustration. When conducting research, this student posed three questions that intuitively instantiated deKleer and Brown's theory: What are the parts? What are their purposes? How do they work together? She explored video of live circulatory phenomena, such as a heart beating in an open chest and blood cells circulating through capillaries, all structured around a schematic of the circulatory system. The student's card sort of parts of the circulatory system was anatomically structured. Her presentation was clear and correct. When asked about the novel surgical technique, she was able to reason about how it would work; more able students in the same classroom study had to be reminded that the heart beat before they could even begin to reason about the technique. From the multiple sources of data collected, Buckley constructed a multilevel expressed model that represented the student's mental model of the circulatory system in terms of parts and behavior, and how the interaction of parts at one level produce the behavior of the higher anatomical level.

The contributors to Gilbert and Boulter (2000) provide multiple perspectives and examples for how model-based learning contributes to the development of mental, expressed and consensus models in science education. Boulter and Buckley (p. 41) developed a typology to support research on how expressed models might contribute to a learner's mental model. They categorize expressed models found in classrooms in terms of the mode of representation employed (concrete, verbal, visual, mathematical, gestural, and mixtures thereof) and the attributes of the representation. Attributes include distinctions between quantitative and qualitative, static and dynamic, and deterministic and stochastic. They illustrated the use of the typology with examples from the solar system and the circulatory system. In order to characterize and define mental models and examine methods for investigating them, Franco and Colinvaux (p. 93) present examples of model revision by describing how Einstein's combination of the concepts of inertial and gravitational mass shaped his work on general relativity. They describe similar examples from children's development of models of the earth. Buckley and Boulter (p. 119) focus on the role of representations (expressed models) in building mental models of the circulatory system and the solar system, because "Phenomena may be hidden within or may be too small, too large, too fast, or too slow for humans to see. Even when phenomena are within the range of the human perceptual system, it can be difficult for learners to detect the parts of a system or model. This is especially the case when directly observing phenomena or images thereof. Nature doesn't come with labels, and boundaries between parts are often indistinct (p. 133)." They examine what aspects of the phenomenon (structure, behavior, or mechanism) are represented and how the particulars of a representation may present semiotic challenges for learners' sense-making. They discuss the difficulties of making clear the components and their interactions in various representational modes and suggest some representational techniques that might help learners overcome the semiotic challenges of a given representation. Reiner (p. 157) discusses the role of mental models in thought experiments, in particular, the use of an imagery strategy. She suggests that thought experiments are a tool for generating, testing, and refining mental models. She explores the nature of thought experiments and of embodied, tacit, non-propositional knowledge. In a case-study, she shows how embodied knowledge is reflected in thought experiments while modeling a situation in a physics problem.

Important Scientific Research and Open Questions

Mental model-building for the purpose of operating in the world is ubiquitous and spontaneous; much of it is unconscious (Johnson-Laird 1983). When it is not, motivation plays an important role in model-based learning (Seel 2003). What motivates a learner to engage in model-based learning? Psychologists who conduct research in motivation have contrasted intrinsic vs. extrinsic motivation, the desire to understand vs. the desire to perform, or spontaneous vs. intentional vs. directed learning. Model-based learning is no doubt influenced by all of these, as well as the epistemology of the learner. If students believe that the illustrations or physical models they encounter in instruction are to be memorized and regurgitated, they are unlikely to invest the effort required to construct mental models of the phenomena being represented (Gilbert and Boulter 2000). If, however, they are motivated by the desire to understand, they will try to construct mental models and pose questions accordingly (Buckley 2000).

The construction of knowledge whether by an individual or a group involves a fluid interaction of mental models, expressed models, and consensus models. Whether this is formalized within a domain such as science or guided in a classroom or engaged in by an individual who seeks to understand, model-building requires cycles of model generation, use, evaluation, and revision. This results in a progression of models, whether historic, naturalistic, or guided by instruction, which produces a network of connected knowledge that can be traversed and examined in diverse ways. This creates a conceptual ecology that influences future learning.

The authors cited in this entry and countless others have contributed to the development of a consensus model of model-based learning and to embedding it in a consensus model of model-based teaching and learning. All call for additional research to validate these models through an eclectic and functional collection of methodologies that enable us to draw inferences about the state of a learner's mental models and their evolution. Model-based learning theory is a powerful organizer for learning, teaching, and assessment. The model of model-based learning is an intermediate model. That is, it must be supported by research in cognition and in the underlying mental representations and neurochemistry. Its utility for designing learning environments, both computer-based and classroom-based, must be examined. Finally, the ramifications for policy-level decisions about standards, assessment, and teacher education must be considered.

Cross-References

► Mental Models
► Mental Models in Improving Learning
► Model-Based Reasoning
► Model-Based Teaching
► Model-Facilitated Learning
► Simulation and Learning: The Role of Mental Models

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Model-Based Learning with System Dynamics

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Synonyms

Computer-based learning environment; Computer-based learning; Flight simulator; Interactive learning environment; Simulation-based instruction

Definition

Model-based learning (MBL) refers to the activity of humans interacting with an external, formal model for the purpose of learning. The external model is used as a point of reference which structures and guides the learning process with the learner.

Model is a simplified representation of a real system. Models appear in this entry in the form of simulation models and mental models. A *simulation model* is an explicit, computer-based representation of essential parts of reality. It provides an environment where a human learner can experiment with hypotheses. Synonyms for simulation models are interactive simulations, microworlds, participatory simulations, interactive learning environments, flight simulators, or computational learning devices.

A *white box model*, also called *glass box* model, is a model about a system where all necessary causal information about the system is available in the model. The model structure and behavior is accessible. Black box models, on the other hand, have only a low level of detail; no information about the model's inner structure is available. A *grey box model* offers a level of detail ranging in between black and white box models.

A *mental model* is a construct of cognitive psychology. Mental models are internal representations of conceptual and causal interrelations among elements that people use to understand specific phenomena. A *mental model of a dynamic system* is a relatively enduring and accessible, but limited, internal conceptual representation of the dynamic characteristics of an external system.

An *expert model* is a representation of essential parts of reality for a situation of interest. The expert model has a high level of fidelity and validity and is substantially free of biases. Such a model can be conceived of as the mental model of human experts who have the best knowledge and insights of a specific part of reality.

Feedback is the transmission and return of information about the current output condition of a system. A *feedback process* is a process by which a system is controlled or changed by the output or response it produces.

Learning is considered a feedback process of the following kind: Our decisions alter the real world, we receive information feedback about the world and revise the decisions we make and the mental models that motivate those decisions. Learning can also be seen as a process of discovering the content and structure of a model or reality.

System Dynamics is a computer modeling methodology that is used to represent and analyze complex nonlinear dynamic feedback systems for the purpose of generating insights and improving system performance. It has its intellectual origins in control theory, management science, and digital computing. It was created in 1957 by Jay W. Forrester of the Massachusetts Institute of Technology as a method to help managers better understand and control corporate systems. Today, it is applied to topics in a wide variety of academic disciplines; see: www.systemdynamics.org and the journal "System Dynamics Review."

Theoretical Background

Relevance of MBL with System Dynamics

It was the Greek philosopher Heraclitus who said that nothing endures but change; thence, continuous learning is pertinent. Learning is, in principle, a feedback process in which our decisions influence reality. As a result, we receive information feedback about the world and revise the decisions we make and the mental models that motivate those decisions. Unfortunately, in the world of social action various impediments slow or prevent these learning feedbacks from occurring, allowing flawed and harmful behaviors to persist. The barriers to learning include the dynamic complexity of the systems themselves; inadequate and ambiguous outcome feedback; systematic misperceptions of feedback, nonlinearities, and time delays; inability to simulate mentally the dynamics of our mental models; and poor scientific reasoning skills. Experimental research substantiates the fact that people have a very poor understanding of even the simplest dynamic systems. To be successful, methods to enhance learning about complex systems must address these impediments. MBL with System Dynamics is one powerful method to address the shortcomings (Sterman 1994).

Content of MBL with System Dynamics

What is meant by MBL is the fostering of a human learning process by means of a computer simulation model. Using external devices as learning tools is as old as mankind. MBL with System Dynamics has been used since 1960s. It concentrates specifically on the interaction of learners with an instructional simulation based on the methodology of System Dynamics. In this contribution, the terms “computation model” and “System Dynamics model” are used interchangeably.

In principle, two modes of teaching can be differentiated: conceptual and procedural. The former focuses on teaching of substantive content; the latter addresses teaching about how to perform something in a substantive area. Educational uses of System Dynamics generally concern the conceptual mode of teaching by which students learn about the content of a system and the mechanisms which govern the behavior of that system. In a computer learning environment, the learner interacts with a computer model which is considered an expert model. This expert model has been built by a programmer in advance of the educational situation. It consists of an embedded set of relationships of a particular domain with a high level of validity and fidelity. Most often, the expert model is supported by additional information and communication technologies by which the learner can investigate the model’s content. A key feature of MBL with System Dynamics is that the information feedback provided by the simulation model depends on the way in which the learner has changed the variables of the simulation model.

Theoretical Basis

MBL with System Dynamics is rooted in Kolb’s *experimental learning theory* and Bruner’s method of *discovery learning*.

Kolb’s *experimental learning theory* (1984) develops a learning process which unfolds over time and iterates through four stages: concrete experience (1), observation and reflection (2), forming abstract concepts (3), and testing them in new situations (4). The learning cycle begins with a person carrying out a particular action and then observing the effects of this action (1). The second step is to understand these effects in the particular instance so that if the same action was taken in the same circumstances it would be possible to anticipate what would follow from this action (2). The third step is to induce the general principle under which the particular instance falls (3). Generalizing may require executing several actions over a range of circumstances to gain experience beyond the particular situation and suggest the general principle. The learning cycle is completed with the testing of the newly acquired abstract concepts in new situations (4).

Bruner’s *discovery learning* (1961) is a method of instruction of self-guided learning behavior. As proposed by this method, students interact with their environment by discovering and manipulating objects, coping with controversies, and executing experiments. Bruner argues that the content which has been acquired by own activities is more readily available and stored more sustainably. Discovery learning takes place in situations where problem solving is required.

Process of MBL with System Dynamics

Ideally, the process of learning with computational models follows a scientific reasoning process: define a problem situation; state hypotheses about the elements causing the problem; design an experiment to test the hypotheses; perform the experiment using the computational model; collect, analyze, and interpret the simulation data; and evaluate and perhaps reformulate the original hypotheses. The formulation and reformulation of the hypotheses help to form a mental model of the problem situation. Hence, by means of the interaction with the computational model, the learner can successively change and improve the hypotheses and hence advance the mental model about the situation gradually. By this process, the students gain a deep understanding of the computational model's substantive content. The computational model is used as an explicit and formal expert model which contains the knowledge that is to be obtained.

In MBL with System Dynamics, the computational models are provided as iconic, graphical representations detailing the causal structure of the underlying system. In most learning environments using System Dynamics, the models are fully accessible by the learners. Besides testing the hypotheses about cause and effect, such environments enable learners also to trace the cause and effect structure and understand the causalities of why the hypotheses could or could not be confirmed. This full access to the causal model structure is a defining characteristic of System Dynamics models. By this, the learner has the potential to understand even counterintuitive system behaviors which are deeply rooted in the dynamic complexity of reality. System Dynamics simulation models are therefore also sometimes called causal white box models with a high degree of validity or fidelity. Other names for computational models are, for example, microworlds or interactive learning environments. The process of MBL using computational models is also referred to as simulation-based discovery learning or simulation-based exploratory learning.

Results of MBL with System Dynamics

The process of MBL with System Dynamics facilitates improving the learner's mental models by engaging in inquiry that is otherwise impractical or even impossible. Through the use of such tools, the cost in time and resources for each learning iteration are reduced. Thus, the number of iterations can be increased with the result of a potentially more detailed understanding of the problem at stake. In addition, computational models can reveal the dynamic complexity of the systems, untangle inadequate and ambiguous outcome feedback, and can help to overcome misperceptions of feedback.

Important Scientific Research and Open Questions

Scientific research about MBL using System Dynamics is diverse and addresses among others the following questions: Does MBL with System Dynamics yield more comprehensive learning? Does model-based learning with System Dynamics result in faster and/or more retentive knowledge? Does guided (re)-discovery of existing models or the creation of own models yield better results? Research about these topics is undertaken by experts specialized in System Dynamics, for example, at the Sloan School of Management at MIT (http://mitsloan.mit.edu/groups/sd/), at the University of St. Gallen (www.systemdynamics.ch), and at the University of Bergen (www.uib.no/rg/dynamics). In the following, relevant research areas are outlined and briefly commented.

Effectiveness of MBL with System Dynamics

The educational value of computer simulations has been accepted as an article of faith. As for any educational method, MBL with System Dynamics has to establish its usefulness and its advantages relative to other teaching methods. It must provide value other methods cannot. Even though qualitative as well as quantitative research with small sample sizes evaluating the process and outcomes of MBL with System Dynamics exists, a large scale systematic research endeavor is still missing. In this, System Dynamics shares the legitimating pressure as other instructional methods.

Until now, it has been shown that the use of computational models frequently induces active learner behavior and constructive learning processes (de Jong et al. 1998). The reason is perhaps that a computational model supports students' scientific reasoning process. Moreover, qualitative studies have shown that MBL with System Dynamics can serve such distinct purposes as to comprehend basic dynamics of a system, to illustrate problems associated with control of complex and nonlinear systems, to offer participants an opportunity to practice group communication and leadership skills, and to gain understanding of time delays (Lane 1995).

Building Versus Using Simulations

A general differentiation in the educational use of simulation is whether one learns by building simulations or by using existing simulations. System Dynamics has historically been based on the former. The alternate approach is to provide students with complete simulations with which they should explore, experiment, and practice. This approach accounts for the major share of existing educational simulation. The models underlying such simulations may be created by designers using System Dynamics software.

Combination of MBL and Other Types of Instructions

Most of the existing research about the effectiveness of MBL has only considered MBL as the sole educational approach used in the classroom. Few researches have demonstrated that students can be stimulated toward deeper learning by means of effective combinations of lectures, cases, readings, and MBL with System Dynamics (Romme 2003). Additional large scale research is required to nurture our understanding of beneficial combinations of MBL and other educational approaches.

Effect of Level of Fidelity and Visibility of a Simulation on Learning Outcome

System Dynamics models can have high levels of fidelity and visibility. Research has found out that learners familiar with the methodology of System Dynamics can use this additional information to their benefit. Without a previous introduction to System Dynamics, such an effect could not be found. The degree of model visibility, that is, the accessibility of the underlying model structure, positively moderates the learning effect of MBL (Alessi 2000).

As problems of interest in reality are usually more complex than a simulation model can represent, the question arises what level of fidelity is required. From a practical perspective, there is a tradeoff between achievable level of fidelity, external validity of the model, and economic feasibility of the construction of the simulation environment. More research about the external validity and transferability of the insights from MBL with System Dynamics is required.

Guided Discovery

Another open question is to what extent the explorative learning should be guided by educational information. To maximize the benefits of MBL with computational models, it has been suggested to structure the learners' interactions with the simulation. In principle, helping the student to conduct concise scientific reasoning and experimentation is already beneficial. This can include such guidance as to focus on specific variables, generate hypotheses about relationships involving these variables, conduct experiments in a systematic way to test multiple hypotheses, and to interpret the results of the simulations with respect to the original hypotheses. Further techniques are to offer predefined hypotheses or provide concrete hints about experimentation with the specific microworld (van Joolingen et al. 1997).

Complexity of the Expert Model

The level of complexity and degree of difficulty of the expert model determines the actual amount of acquired knowledge. The degree of difficulty of a learning simulation negatively impacts on the amount of acquired knowledge. This is contingent on the type of knowledge: Quantitative knowledge about causal relations is more negatively influenced by more difficult computer simulations than semi-quantitative; semi-quantitative is stronger, negatively influenced than qualitative knowledge (Kluge 2008; Moxnes 2004). The drawbacks of simulations with high complexity and high degrees of difficulty can be counterbalanced by more learning iterations and more informative decision aids, for example, an accessibly designed interface.

Besides guiding and controlling the learning process, another method to stimulate the motivation of learners is to provide the learner a succession of expert models which increase in their dynamic complexity. With the succession of simulation models, the level of task difficulty increases accordingly leading to a progressive acquisition of the knowledge and skills of the domain.

In general, the publication history shows an upward trend leading to a significant revivification of interest in MBL using System Dynamics especially in the field of management education.

Cross-References

- ► Computer Simulation Model
- ► Computer-Based Learning Environments
- ► Computer-Enhanced Learning and Learning Environments
- ► Discovery Learning
- ► Feedback and Learning
- ► Guided Discovery Learning
- ► Interactive Learning Environments
- ► Mental Model
- ► Mental Model of Dynamic Systems
- ► Model-Based Learning
- ► Simulation-Based Learning

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Model-Based Reasoning

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Synonyms

Deductive schemas

Definition

Model-based reasoning is a theory that attempts to describe the psychological processes that are used when making a logical inference from a given set of premises. Mental models are schematic representations of possible outcomes that are consistent with premises, using internal tokens to represent classes of events or objects. The semantics of logical connectives (if, or, etc.) determine the way that the representation is structured. Combining premises produces a limited set of possible outcomes from which potential conclusions can be read off.

Theoretical Background

A mental model is a simplified internal representation of some aspects of the world that is used as a cognitive simulacrum in order to allow the cognitive system to predict future outcomes. The idea of a mental model was first proposed by Kenneth Craik in 1943. Models contain only critical dimensions of whatever is to be understood, without having to consider the full complexity of real phenomena. Thus mental models allow the cognitive system to simulate aspects of the real world in a compact way. The idea of using mental models to explain deductive reasoning was proposed by Philip Johnson-Laird in 1983. Deductive reasoning refers to the ability to draw logically necessary conclusions from initial premises that are considered to be true. Simple forms of deductive reasoning present an initial major premise which includes a logical connective linking two states (if P then Q, P and Q, etc.), followed by a minor premise which specifies the truth value of one of the states (Q is false). The mental model theory of reasoning proposes that people use mental tokens to represent combinations of states that are possible for a given major premise. A model is a single combination of tokens representing one possible combination of two (or more) states. For example, the major premise "P and Q" is represented by a single model:

$$P \quad Q$$

The major premise "if P then Q" is represented by three models:

$$P \quad Q$$
$$\neg P \quad Q$$
$$\neg P \quad \neg Q$$

where the $\neg$ symbol is used to indicate negation. The models used to represent the major premise can then be scanned for models which are consistent with the minor premise. The first such model will indicate a potential conclusion. Although there is a certain tendency for this conclusion to be accepted, a key component of the theory is a search for alternatives. Specifically, this is a process by which a reasoner will then attempt to scan for models which are consistent with the minor premise, but which contradict the potential conclusion. If such a model is detected, then the conclusion will be rejected, otherwise the conclusion will be accepted. For example, when reasoning from the premises "if P then Q – P is true," the three models representing the "if P then Q" premise are scanned for models in which P is true. The first model is such a case, which suggests the conclusion that Q is true. No other model exists in which P is true, so "Q is true" is given as the conclusion. In contrast, when reasoning from the premises "if P then Q – Q is true," this representation is scanned for models in which Q is true. In the first such model P is true, which becomes a potential conclusion. However, there is a second model in which Q is true, but in this case ¬P is true. In this case, the search for alternatives results in the rejection of the initial potential conclusion that P is true, and the reasoner will conclude that there is no necessary conclusion. If a given potential conclusion is rejected in this way, the cycle involving identification of potential conclusions and the subsequent search for alternatives can be repeated.

Each model represents a "true" combination of states in the logical truth table corresponding to the connective used in the major premise. This is a critical dimension of the model theory, which assumes that people generally reason by considering potentially true states of the world that are consistent with a given major premise, that is, what might be true. They will generally not consider states that are not possibly true given this premise. While the fully implemented model procedure will lead to a logically valid conclusion, considering only potentially true combinations of states reflects a general characteristic of human reasoning, which is the tendency toward confirmation. The ability to reason from what is impossible is difficult and rarely seen in ordinary reasoning. Thus the overall structure of model theory provides a way of accounting for the ability to derive logical conclusions, without postulating the use of procedures such as reductio ad absurdum which requires explicit consideration of impossibility.

Although in theory reasoning based on mental models should lead to logically correct conclusions, variability in logical performance is accounted for in several ways. Most critical is the fact that the models used for reasoning are retained in working memory and require active use of cognitive resources for their generation and manipulation. Since working memory has a limited capacity, reasoning with more than a single model has the potential to create a cognitive overload, leading to production of nonlogical conclusions. In fact, model theory predicts that the difficulty of a given inference (i.e., the probability of producing the logically correct response) is directly related to the number of models required to fully represent the premises. Use of restricted working memory capacities is related to another important postulate of the theory, which is the principle of economy. In order to limit the use of working memory, the reasoning process is assumed to start with a limited representation of the major premise. This represents only possibilities in which the antecedent is true. The existence of other possibilities is acknowledged by a mental footnote, which may or may not be expanded. In the often-studied case of if-then inferences, this is a single initial model representing the antecedent and the consequent only. For example, the premise "if P then not-Q" would generate the initial model:

$$\begin{array}{cc} P & \neg Q \\ & \ldots \end{array}$$

The symbol (. . .) represents the notion that there exist other, implicit, models that must be specified in order to generate a complete representation of the premises. Reasoners are assumed to prefer using the initial model in order to generate conclusions. This would allow rapidly concluding that, for example, "if P then not-Q – P is true" leads to the conclusion that Q is not true. Similarly, the minor premise "Q is not true" leads to the conclusion that P is true. If no model is found that is consistent with the minor premise, then no conclusion is possible. Use of the initial model allows making rapid, low-cost inferences while liberating working memory resources for other operations. However, the resulting conclusions are not reliably valid. People will sometimes produce a conclusion that is logically false or reject a conclusion that is logically true by relying on initial models.

Under some conditions, which are not fully specified, people will complete the initial model in a process referred to as "fleshing out." Fleshing out requires accessing a semantic representation of the connective used in the major premise which will allow incorporation of additional models consistent with this premise into the full representation used for generating inferences. Under ideal circumstances, this will access the core meaning of the connective, which corresponds to its full decontextualized semantic representation.

However, various forms of interpretational processes can affect which models are actually included in the final representation. By a process referred to as pragmatic and semantic modulation proposed by Johnson-Laird and Byrne in 2002, people are assumed to use contextual and/or semantic cues to access alternative representations of a given connective, resulting in different model sets. One very clear example of interpretational variation concerns reasoning with conditional (if-then) promises. When given a promise of the form: "If you cut the grass, then I will give you $5," people strongly tend to infer that cutting the grass implies receiving $5, and vice versa. Model theory would account for this by assuming that the common interpretation of conditional promises leads to the following restricted model set:

$$\begin{array}{cc} P & Q \\ \neg P & \neg Q \end{array}$$

In other words, common interpretations of conditional promises lead people to assume that the combination of not cutting the grass and receiving $5 is not consistent with the meaning of the promise, and this combination of states is not used when reasoning in this case.

Human reasoning is notoriously variable, and often nonlogical. Mental model theory starts from the supposition that people have access to the core meanings and the basic representational skills required to make logical inferences. Variability in reasoning is accounted for by limited working memory which restricts the ability of many people to make more complex inferences, and promotes the use of an initial, limited, model set which can also lead to nonlogical responses, and by the effects of interpretational factors. Thus, model theory assumes a basic human competence for logical reasoning, and explains variation from logical norms by a variety of secondary, performance factors.

Important Scientific Research and Open Questions

The model theory of reasoning has been used to explain a wide variety of phenomena in human reasoning, although there is a great deal of controversy about its adequacy. Some of the key postulates of the theory have received at least some empirical confirmation. The first set of predictions concern the key role that is played by working memory in reasoning according to model theory. There is clear evidence that the relative difficulty of inferences is correlated with their complexity as measured by the theoretical number of models required for a full representation of premises. In addition, individual differences in working memory predict the relative ability of people to make correct logical inferences on problems involving different numbers of models. The theory has also been used to make some predictions about the development of reasoning abilities in young children, based mostly on the idea that children's limited working memory capacities will limit the complexity of the model sets that they can theoretically manipulate.

Model theory has predicted that the use of initial models to make inferences on complex problems will result in strong tendencies for people to make specific false inferences for a variety of forms of reasoning. However, evidence for initial model use in simple if-then reasoning is much less clear. Another important postulate is the search for alternative models. There is some evidence that people will actively search for disconfirming instances when reasoning, although this is not universally true. In addition, the tendency to search for alternatives varies greatly between individuals, and instead of being universal, may be a characteristic of more competent reasoners. The theory has also been expanded to include explanations of probabilistic reasoning and consistency.

While the several postulates of the theory have received much empirical confirmation, there are some key aspects that remain open. Possibly the most critical of these concerns the way that variation in reasoning related to content is explained. Model theory assumes that such variation is a product of modulation which implies that a basic core meaning is adjusted by contextual or semantic factors which function at the level of model selection. However, more recent theories of familiar reasoning assume that the essential component of reasoning is a probabilistic evaluation of the likelihood of a conclusion being true. Such a process would involve an active search through a reasoner's statistical knowledge base about the world in order to produce an estimate of the probability of a conclusion being true. Related to this is a very basic question about the nature of people's semantic representations of logical connectives. The most often studied of these is the if-then conditional. Model theory assumes that the core semantic representation of conditionals involves representing the true cases of the corresponding truth table, which does not include the P ¬Q model. However, probabilistic theories assume that the base meaning of conditionals involves the relative frequencies of P Q and P ¬Q cases.

Cross-References

► Models and Modeling in Science Learning
► Normative Reasoning and Learning

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Model-Based Scene Interpretation by Multilayered Context Information

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Synonyms

Hierarchical graphical model; Place and object recognition; Scene understanding; Visual context

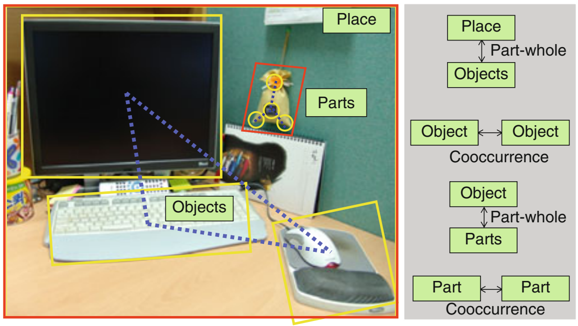
Definition

Automatic scene understanding is the final objective in computer vision like human visual systems. In general, a scene image consists of visual components such as background and multiple objects. The background can be a meaningful place. Visual elements are not independent but strongly interrelated. Assume that a street scene where cars, humans, trees exist. Cars run on the road, humans walk on the sidewalk, and trees are around the street. We call the visual interrelation as visual context in computer vision. Especially, we call it as multilayered context if there are multiple contexts such as place-object, object-object, object-part, part-part context. Human visual systems use the visual context frequently for accurate and fast scene understating or ► scene interpretation. Likewise, the visual context can be mathematically modeled using graphical model. It is the combination of graph theory and probability theory to handle both the relation and uncertainty. Visual models are necessary to recognize backgrounds and multiple objects in scenes. In a graphical model, we can build graphs by learning and understand scenes by inferencing.

Theoretical Background

The research of visual context of human visual system is traced back to the pioneering work conducted by David Marr, a British neuroscientist and psychologist (Marr 1982, pp. 196–197). In the Marr's Vision, there are inter-element interactions among spatial elements in human visual system. The interaction can be used to the correspondence strength in stereo match. Such kind of lateral interaction is called *spatial context*. Recently, Moshe Bar found specific mechanisms of the contextual facilitation of object recognition in human visual systems (Bar 2004). Although much has already been revealed about the cognitive and cortical mechanisms that serve recognition of individual objects, surprisingly little is known about the neural underpinnings of contextual analysis and scene perception. A recurring proposal is that prototypical context might be represented in structures that integrate information about the identity of the objects that are most likely to appear in a specific scene with information about their relationships. A typical scene structure that follows physical and contextual semantic rules facilitates recognition. When subjects are presented with a scene of a familiar context, such as bathroom, objects that are consistent with that context (such as a drier) are recognized more easily than object that would not be expected in the context (for example, a guitar).

These findings support the idea that context facilitates object recognition by activating place recognition (hierarchical context: place recognition → object recognition). Likewise, place recognition can be facilitated by recognizing objects (hierarchical context: object recognition → place recognition). Context also facilitates the recognition of related objects even if these objects are ambiguous when seen in isolation. An ambiguous object becomes recognizable if another object that shares the same context is placed in an appropriate spatial relation to it (spatial context: object ← → object). In general, there are two kinds of visual context such as spatial context and hierarchical for static images. Spatial interaction among objects or parts can be regarded as spatial context. Part-whole interaction between a place and objects or an object and parts can be regarded as hierarchical context. As presented by Bar, the visual facilitations are not unidirectional but bidirectional way.



The visual context for scene understanding can be mathematically modeled using the *graphical model* (Jordan 1999). Graphical models are a marriage between probability theory and graph theory. They provide a natural tool for dealing with two problems that occur throughout applied mathematics and engineering – uncertainty and complexity – and in particular they are playing an increasingly important role in the design and analysis of machine learning algorithms. Fundamental to the idea of a graphical model is the notion of modularity – a complex system is built by combining simpler parts. Probability theory provides the glue whereby the parts are combined, ensuring that the system as a whole is consistent, and providing ways to interface models to data. The graph theoretic side of graphical models provides both an intuitively appealing interface by which humans can model highly interacting sets of variables as well as a data structure that lends itself naturally to the design of efficient general-purpose model. So, the visual context for scene understanding can be modeling using the directed graphical model (example Bayesian Net) or the undirected graphical model (Markov Random Field) depending on the contextual relationship.

Important Scientific Research and Open Questions

For a long time, mechanisms of human visual system for scene understanding were special topic of psychology, psychophysics, and neurophysiology. Although partial low level processing mechanisms are revealed but most of the scene understanding mechanisms are unknown due to difficulties of experiments VanRullen 2003). So, one important direction of scientific research for scene perception is to find the detailed mechanisms of human visual system especially the intermediate processing that connects low level visual information to high level scene understanding.

Another popular research field of scene understanding is computer vision and robotics. The research objective of computer vision is to make a human-like vision system using a camera and a computer. So, one important research direction is to model mechanisms of human visual system mathematically and to validate its performance in real-world environments. Gabor filter and Canny edge detector are well-known examples motivated from the mechanisms of low level visual processing of human visual system (Canny 1986). They focused on the physical mechanisms of receptive field V1 of human visual system and modeled mathematically using exponential function, sine, cosine, or Gaussian function. Likewise, vision-based scene understanding system can be built motivated from findings of human visual system. One example of recent finding about high level visual perception is visual context (Bar 2004). Objects in a scene do not stand alone but facilitate each other (spatial context). Scene information such as place can be useful to discriminate ambiguous objects. Recognized object information can be useful to the recognition of place of current scene (hierarchical context). So, one important property of visual context is bidirectional facilitation in scene understanding. Feasible realizations of visual context for scene understanding are hierarchical graphical model-based approaches proposed by Kim and Kweon (2007). Both approaches can detect multiple objects based on graphical model. However, there are several scientific issues such as unknown graph structure (varying number of visual elements) and inaccurate segmentation and recognition. Moreover, object categorization is still an unsolved problem in scene understanding. If scene understanding method is established, this can be realized in robot vision of service robot, surveillance system, smart car, and military area.

Cross-References

► Bottom-up- and Top-down Learning
► Categorical Learning
► Categorical Perception and Supervised Learning
► Collaborative Learning
► Computational Models of Human Learning
► Context and Semantic Sensitivity in Learning
► Human Cognitive Architecture

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Model-Based Teaching

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Synonyms

Model-centered instruction

Definition

Model-based teaching is instruction designed to support the development and evolution of learners' mental models. We define mental models as internal representations of integrated knowledge that include components of a dynamic system and their interactions, which produce some emergent behavior or property. Learners build, extend, elaborate, and improve the accuracy and completeness of their mental models, much as science extends our understanding of the world about us. Settings may be formal classrooms or informal learning activities. Teaching philosophies may range from didactic to discovery and may employ instructional strategies and tactics that operate over months of instruction to those that operate over seconds (Clement and Rea-Ramirez 2008; Gilbert and Boulter 2000).

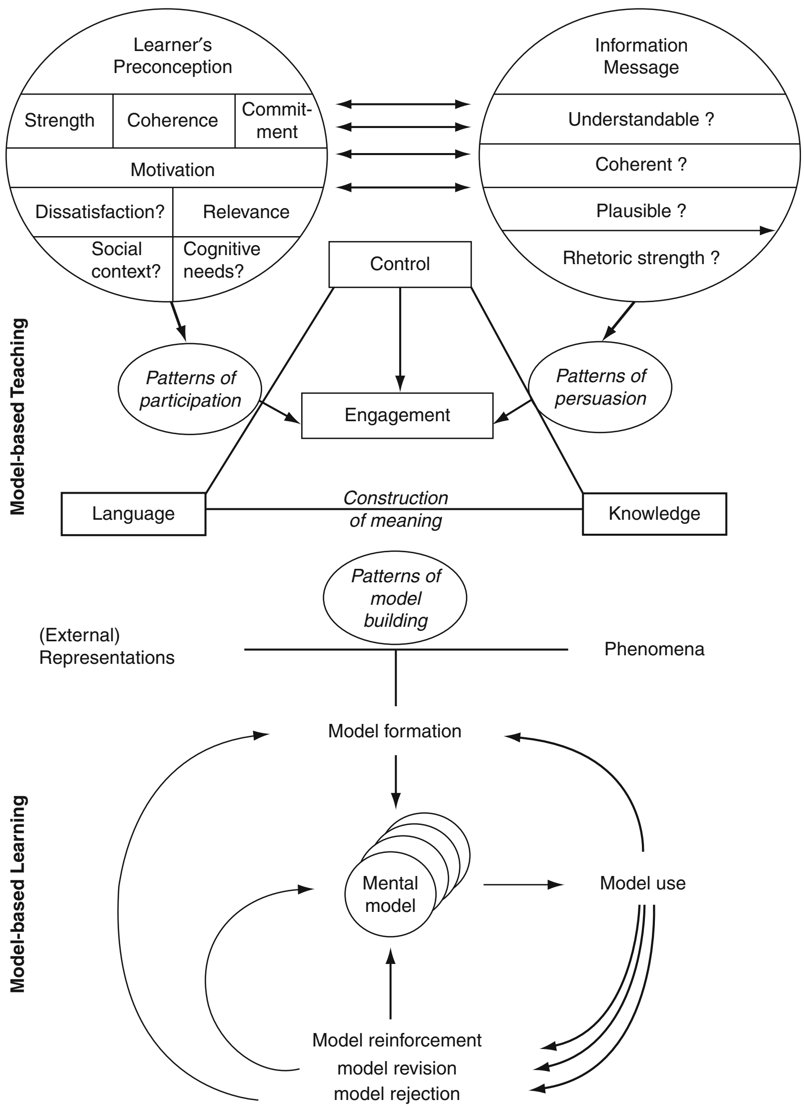
Theoretical Background

The core beliefs of model-based teaching are the assumptions that "*mental* modeling is a universal way of thinking, that *expressed* models are a universal component of communication, and that *consensus* models are produced by all social groupings that have some degree of permanence" (Gilbert and Boulter 2000, p. 343). Both expressed and consensus models are external representations that interact with mental models. The use of external models in model-based teaching is common. Mayer (1989) focused on the use of conceptual models (external) and their role in helping students build mental models of the systems they study. He concluded that conceptual models can improve students' systematic thinking and their ability to solve transfer problems, and urged the use of dependent measures such as conceptual recall, verbatim retention, and problem-solving transfer as more sensitive measures of systematic thinking. He argued that a good conceptual model (external) should be complete, concise, coherent, concrete, conceptual, correct, and considerate of the learner (pp. 59–60).

Stewart and colleagues (2005) focus on inquiry and problem-solving as instructional strategies through which students develop, evaluate, and reject, revise, or elaborate their mental models. Students are given problems or tasks that require reasoning not only from cause-to-effect (e.g., making predictions) but also from effect-to-cause (e.g., explaining observations). In the process of forward and backward reasoning, students test and evaluate their models against data, which in turn leads to model revision or elaboration.

In addition to writing on the nature and significance of models and modeling in science education, the researchers of the Centre for Models in Science and Technology (CMISTRE) focused on external consensus models used for teaching and learning and their role in the development of learners' mental models (Gilbert and Boulter 2000). The researchers describe the role of external models in explanations in chemistry and physics and biotechnology. They also describe how they function as a critical part of discourse in classrooms, in computer modeling of phenomena, and in the development of teachers' pedagogical content knowledge. This work contributed much to the growing research and theory base of model-based learning.

Seel (2003) extended the definition of model-based teaching and learning that combined the work of Buckley and Boulter (Gilbert and Boulter 2000, pp. 122 and 304), as shown in Fig. 1. In particular, he expanded the learner characteristics beyond prior knowledge to include affective and cognitive factors that influence not only the learner's interpretation of the information message (which he also expanded and articulated), but also patterns of participation and persuasion in the construction of meaning that takes place in classrooms and other learning contexts. Informed by Mayer's work (1989), Seel and his colleagues (2003) investigated the



Model-Based Teaching. Fig. 1 The interplay between model-based learning and instruction (Seel 2003, p. 73) effectiveness of providing a conceptual model at the beginning of the learning process and the long-term impact of a multimedia learning program that was guided by cognitive apprenticeship approach. Their investigations focused on a learning-dependent progression of mental models. Through the use of learner-generated causal diagrams, they examined both the acquired domain-specific knowledge and the stability of the initially constructed mental models, conducting five replication studies. They found that the learners' mental models were not intact adoptions of the external conceptual models presented during instruction. Rather, they concluded that the learners' mental models were constructed *when needed* (author's emphasis) to deal with a particular situation.

Clement and Rea-Ramirez (2008) expand our understanding of teaching strategies and techniques in a collection of research studies that took place in classrooms focusing on a similar evolution of mental models. Their contributors describe student–teacher co-construction of mental models in a variety of domains and focus on a wide range of teaching strategies and techniques. Effective model-based teaching begins with an integrated target model (an age-appropriate version of the expert consensus model) and an effective learning pathway. While traversing this pathway, both students and teachers contribute elements to the expressed models. They describe a pathway that begins with students' models, usually expressed as drawings, followed by cycles of model criticism and revision. The stimuli for revision range from discrepant questions to experiments that demonstrate the shortcomings of a mental model. Throughout the studies, teachers set the agenda and decide which of the revisions to address at what time. Ideally, students are kept in a Vygotskian-like "reasoning zone," which Clement and Rea-Ramirez define as "an area of discussion where students can reason about ideas and construct new ideas productively" (p. 19). When the discussion ranges outside the reasoning zone, the teacher must provide enough support to bring it back into the zone. Teachers may scaffold students' reasoning with a "leading question, hint, new observation, reference to an earlier comment, discrepant question or piece of information" (p. 19). This requires a skillful teacher and decisions made in the midst of discussions.

Clement and Rea-Ramirez tie these studies together into an organizing framework that expands the definition of model-based teaching and learning. They begin with two main goals: finding an appropriate learning pathway toward an age-appropriate target model and finding teaching strategies that help students move along that pathway. They assert that, "Pathways that stretch across large topic areas, such as different systems in the human body, set up the important goal of making a curriculum coherent by integrating the student's knowledge into an interconnected framework of ideas" (p. 257). Clement (p. 255) articulates six levels of organization for curriculum design and teaching. He charts both goal structures for learning outcomes and teaching strategies relevant to that level organization. At the highest level (6) the focus is on curriculum integration studies intended to help students develop integrated target models across units, which has implications for sequencing and connecting units. The lowest level (1) focuses on dialogical tactics intended to promote active idea sharing and social norms for discussion in science class and implemented by the teacher in less than 20 seconds. In between these extremes, the goals and strategies focus on the progression of intermediate models that comprise the learning pathway for both planning and implementation. Strategies that come into play at the different levels include introducing problems, building model parts, facilitating syntheses, as well as observations and teacher moves that stimulate the cycles of model generation, evaluation, or modification needed to move students' mental models forward.

Horwitz and colleagues (2010) created a complex multilevel model-based learning environment for genetics. At the heart of the genetics environment is a multilevel computer model of transmission genetics that ranges from DNA molecules to pedigrees. All are represented in computer models that are linked, so that changes in the DNA base pairs may result in allele changes that may result in changes in observable characteristics of the organism (dragons), and could result in heritable traits. Based on earlier work with GenScope, they embedded these models into a series of learning activities intended to help students build increasingly complex mental models. They provided scaffolding that supported the learner's interpretation of the representations, drew attention to the relevant model information, and set forth a series of tasks intended to stimulate construction and modification of mental models. Learners were also asked to reify and reflect on their understanding in textual form. Within a learning activity, the tasks became increasingly complex and the scaffolding decreased. The ultimate task for these learners was to determine the genotypes of two invisible dragons through breeding experiments. A key feature of the environment was that the system monitored student answers and actions, and provided specific feedback as students progressed through each activity. This feature also enabled Horwitz et al. to embed assessments seamlessly into the learning activity and provide immediate feedback, as well as reports for teachers and researchers. They demonstrated the feasibility of this model-based instruction in large-scale studies that involved nearly 2,000 students in over 70 biology classrooms worldwide.

Important Scientific Research and Open Questions

A common theme among the researchers cited here is the need to specify learning pathways that start with naïve or alternative conceptions and progress through a series of intermediate models that lead to a target model, which in turn can be considered on the path to the expert consensus model. Is there an optimal learning pathway or are there many paths to the same target model? Are some paths more productive than others?

Another common theme is the creation of a "comprehensive and empirically valid theory of instructional design of model-centered learning in various instructional settings" as expressed by Seel (2003, pp. 80–81), but echoed by all. How does one use model-based teaching and learning theory to create effective museum displays or intelligent tutoring systems or curricula or to guide classroom discourse? These authors have provided us with a wide range of examples. We cannot do any of this work without the ability to assess learner's mental models, or as Seel (2003) quotes Scandura, "any theory of teaching and learning must include some way of finding out what students know at any phase of learning" (p. 80).

The theory of model-based teaching and learning has significance for a wide range of educational endeavors. At the policy level, it suggests that we should be framing our standards more explicitly as target models that stretch over large topics rather than fragmented propositional knowledge. This has ramifications for large-scale, high stakes assessments. If we value model-based learning, then we should be assessing the extent of students' models and their ability to engage in model-based reasoning and inquiry. We also need to educate teachers so that they can help our students do well on such assessments by supporting mental model-building and by making model-based learning an explicit and taught learning strategy and skill. None of these are easy tasks, but they are important complex work that needs to be done. In order to accomplish this work, we need research that ranges from brain-based and cognitive research on the processes of model-building to classroom-based research and beyond to high-stake assessments.

Cross-References

► Mental Models
► Mental Models in Improving Learning
► Model-Based Learning
► Models and Modeling in Science Learning

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Model-Building

► Model-Based Learning

Model-Centered Instruction

► Model-Based Teaching

Model-Centered Learning

► Mental Models in Improving Learning

Model-Facilitated Learning

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Synonyms

Graduated complexity; Model-based learning; Problem-centered learning; Situated learning

Definition

Model-facilitated learning (MFL) is learning that is centered around and facilitated by models in the form of expert and student representations of a problem or problem space, a solution approach, and/or a solution. The models may or may not be created by learners, but learner interaction with models is generally considered critical to the learning process.

Theoretical Background

MFL is an instructional approach that integrates learning theory (e.g., socio-constructivist epistemology), representational methodology (e.g., system dynamics modeling), and educational technology (e.g., interactive, collaborative simulations) in a systematic manner to guide the planning and implementation of instructional curricula (e.g., learning activities, units of instructions, sequences of lessons). The particular emphasis in model-facilitated learning is on improving understanding with regard to complex and challenging learning tasks and problem-solving situations. Complex learning tasks are those that tend to have many interacting components, some of which may be incompletely defined, and with some nonlinear relationships and delayed interaction among the various components. Such problems occur in economic forecasting, engineering design, environmental planning, management decision making, and many other situations that are encountered every day. Using models of complex phenomena to help learners gain a holistic and meaningful sense of the problem is one aspect of model-facilitated learning (MFL). Having learners engage in modeling activities to gain insight into the complexity of a problem situation is a second aspect of MFL. MFL assumes three stages of learning development and has associated instructional guidelines for each stage (Milrad et al. 2003). The first stage is problem orientation in which problems or related sets of problems are presented to learners and learners are asked to solve relatively simple versions. The second stage of learner development involves inquiry exploration in which learners are challenged to explore a complex task domain and asked to identify and elaborate the relationships among the various components of the problem. The third stage of learner development involves policy development in which learners are asked to reason in a more global and holistic perspective with regard to rules and heuristics to guide decision making concerning various problem situations that may arise in that task domain. Principles to guide the elaboration of learning activities and instructional sequences within these stages include such notions as (a) situating the learning experience in the context of meaningful and realistic problems (Merrill 2002), (b) presenting problems of increasing complexity, involving learners in a sequence of related tasks involving the initial problem scenario (van Merriënboer and Kirschner 2007), (c) involving learning in an increasingly set of complex inquiries and explorations with regard to the problem situation, and (d) challenging learners to develop rules and guidelines to guide decision making in anticipated problematic situations.

The foundations for model-facilitated learning are derived from system dynamics (see, e.g., Sterman 1994), educational and learning psychology (see, e.g., Lave and Wenger 1990; Spiro et al. 1988), and from instructional design (see, e.g., Merrill 2002). In addition, MFL integrates the principle of graduated complexity (Milrad et al. 2003) in the form of guidance for the elaboration of instructional sequences. According to this principle, instructional sequences should challenge learners to:

1. Characterize the representative behavior of a complex system, indicating how it behaves over time
2. Identify a desired outcome and key variables and points of leverage with respect to attaining that outcome

3. Identify and explain alternative causes for observed phenomena
4. Reflect on how the system and associated variables seem to change over time and through interventions
5. Develop a rationale to explain complex phenomena in terms of an underlying system structure, including decision-making and policy formulation guidelines
6. Broaden understanding through diverse and new problem situations

Important Scientific Research and Open Questions

What is not known in a general way is how best to support the development of expertise and insight with regard to complex problem-solving activities. How well instruction created in accordance with the principles of MFL, especially in comparison with other instructional methodologies, has not been established. Which kinds of models (student-created, expert-created, partially complete, etc.) are effective with different learners and learning tasks is also not well known. While versions of MFL have been implemented and evaluated in the first two stages indicated above (problem orientation and inquiry exploration), very few MFL environments exist to promote learning at the last stage of learner development (policy development). As a result, research on effective MFL techniques to promote policy development knowledge remains very open for further research and development, and additional research is needed in the first two stages as well. Additionally, effective MFL instructional sequences for complex problem task domains is not very well established. A central underlying problem concerns the need for well-developed means to assess the progressive development of student understanding in complex task domains. This requires validated means to elicit and evaluate student models in response to problem scenarios, yet those means are still in the early stages of development.

Cross-References

► Belief Formation
► Complex Learning
► Complex Problem Solving
► Expertise
► Situated Learning

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Modeling

► Mathematical Models/Modeling in Math Learning
► Social Learning

Modeling and Simulation

► Simulation and Learning: The Role of Mental Models

Modeling Microgenetic Data

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Synonyms

Microdevelopment

Definition

The main aim of microgenetic studies is to examine change as it is occurring. These studies involve intensive observations of behavior over a period of development and yield rich datasets that tap into the processes of change. One of the challenges that researchers face is how to analyze such complex datasets. One solution is to employ statistical modeling techniques. A modeling approach allows us to take into consideration the true characteristics of the data without violating the assumptions of more traditionally used methodologies such as Analysis of Variance (ANOVA).

Theoretical Background

Repeated-measures ANOVA is accepted within the learning sciences as the standard approach to the analysis of experiments with longitudinal designs. Microgenetic studies share the feature of repeated observations with longitudinal studies (although microgenetic data are collected over a much shorter period of time) and as a result have commonly shared the same methods of analyses. The usefulness of repeated-measures ANOVA is that it can track patterns of change over time and can also identify differences between groups of participants within such a framework. However, for microgenetic data, the use of ANOVA is problematic.

Microgenetic data often do not adhere to the assumption of normality required for the use of ANOVA. It is common for participants to be performing near floor in early sessions and near the ceiling in later sessions. Therefore, microgenetic data are often skewed and has different patterns of variance over time.

A related issue is that ANOVA assumes that there is constant variance between individuals and within individuals. When participants' scores are near floor or ceiling it is more likely that there will be lower variance than when participants return more central scores.

Microgenetic designs may not be balanced with differing numbers of measurements at different times for each individual. ANOVA cannot deal with this issue.

Finally, ANOVA works by decomposing the variance within datasets. Microgenetic hypotheses regarding change may be better tested through parameter estimation, which has fewer constraints and can thus highlight subtleties within developmental data.

Other experiments will yield datasets without a normal distribution and are commonly analyzed using non-parametric methods such as Wilcoxon signed test or Friedman's test for repeated measures. However, their emphasis is on simple hypotheses that are unable to take into account aspects of microgenetic data such as random effects, complex model specifications, and other dependence structures. Their emphasis on ranks does also not provide the flexibility needed to examine hypotheses relating to change.

Important Scientific Research and Open Questions

Statistical modeling is becoming a more popular way of addressing research hypotheses without violating assumptions of more traditional forms of analyses. By modeling data we have more control over how it is analyzed, for example, we can specify an alternative distribution if the data do not conform to a normal distribution (such as a binomial or Poisson distribution) and examine differences between experimental conditions that do not have the same number of observations. The software used to model data includes R, SAS, MPlus, and GLIM4. They allow the user to take control of how the data is analyzed by specifying any number of commands, rather than using a preset one-size-fits-all selection in a typical statistics package. Specification of models is therefore more complicated but texts have been written that describe the procedures (e.g., Moskowitz and Hershberger 2002).

Common issues that arise when specifying a statistical model that are more particular to microgenetic data include individual variability, experimental design, the trajectory of performance and how performance is related to scores at different time points (dependence structure).

Individual variability. Microgenetic experiments follow the same individuals over a period of learning. When specifying a statistical model we are able to include a "random effect" that can account for the variability that is attributed to an individual participant.

Experimental design. The one thing that microgenetic studies have in common is that they include repeated observations of participants over time. However, within these studies the experimental design can vary greatly. There may be different experimental conditions, different skills being tested at different time points, and different periods of time between observations. Unlike ANOVA it is possible for statistical models to compare groups of participants who have different number of observations over the same period of time. This is useful for control groups who may be tested at the first and last time points of a microgenetic study (to check for any "natural" learning over the same time period) with the experimental groups being tested additionally on a number of other occasions in between.

Dependence structure. Another advantage of statistical modeling is that we are able to test whether performance is dependent upon the experience at that specific time point or whether there is a lag effect, in that performance at one point in time is dependent upon scores at a previous time point.

Trajectory of performance. When examining learning of a particular phenomenon we often predict that participants' scores will improve over time. Statistical modeling can allow us to test predictions of different trajectories of change during different periods of microgenetic development. For example, we might predict gradual improvement until a strategy is discovered, followed by a sharp increase in performance, followed by a plateau. We can specify "change points" in a statistical model that mark the points at which a trajectory may change gradient and we can also test whether these changes in trajectory are consistent between groups. One of the main benefits of including change points is that we do not smooth out the subtle patterns of development that can occur when using less sophisticated methods such as repeated-measures ANOVA.

The term statistical modeling can encompass a wide range of techniques. Two examples of where statistical modeling can be used with microgenetic data are quasi-binomial logistic regression models and latent transition models.

Quasi-binomial logistic regression modeling. Logistic regression can be used as a base for modeling microgenetic data (see Cheshire et al. 2007 for a detailed example). The standard logistic regression technique can be modified by specifying the type of distribution (e.g., quasi-binomial – a binomial distribution is useful for examining data with a number of yes/no outcomes. It can be modified to allow for differing difficulty between items), adding change points, a random effect, and combining experimental groups to identify the most parsimonious model. These models can examine change over time and group effects without violating assumptions of the technique.

Latent transition models. Latent Transition Analysis (see Collins and Lanza 2010) is particularly good for analyzing data from microgenetic experiments with a single condition. Similar to factor analysis, Latent Class Analysis identifies common features in the observed data to separate participants into groups. These latent "classes" are mutually exclusive and exhaustive. For example, in an experiment examining strategy usage, participants may be separated into three categories: user of optimal strategy, user of suboptimal strategy, and those who fail trials. Each participant has a probability of belonging to one of these groups.

Latent Transition Analysis extends Latent Class Analysis for repeated measures data. Latent Transition Analysis examines change over time by identifying latent statuses (as opposed to classes, as they can be transitioned in and out of) across the time points. The probability of a participant belonging to a latent status at each time point is identified, as well as the probability of belonging to a status at a time point depending on membership of a status at another time point. Other factors such as order of tasks, performance at specific time points, and participant demographics can be added as covariates.

These are not the only types of models that have been employed to examine microgenetic data. Other models include fuzzy sets modeling (van Geert 2002) and graphical chain modeling (Edwards 2000). One potential problem of statistical modeling is that it is possible to construct complex models that involve as many variables and interactions as there are participants. It is important that modeling techniques are used to test existing theoretical claims rather than to search for spurious associations. However, a modeling approach, when used with care, allows for greater confidence in the interpretation of microgenetic data as the analysis can be pursued without having to violate basic statistical assumptions.

Cross-References

- ▶ Measurement of Change in Learning
- ▶ Microgenetic Method
- ▶ Modeling Microgenetic Data
- ▶ Simulation and Learning: The Role of Mental Models
- ▶ Simulation-Based Learning

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Modeling, Rehearsal, and Feedback

► Behavioral Skills Training and Skill Learning

Models

► Mathematical Models/Modeling in Math Learning

Models and Modeling in Science Learning

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Synonyms

Conceptualization; Simulation; Visualization

Definition

Models are physical, computational, or mental constructions that are intended to represent some other thing, set of things, or phenomena. *Scientific models* in particular are tools for expressing scientific theories in a form that can be directly manipulated, allowing for description, prediction, and explanation. For example, a biology teacher might show students a plastic replica of a human heart, identifying the ventricles and their relative locations. The replica is not an actual heart, but rather a sculpted reproduction that is intended as an educational tool. This type of model can be handled by students, perhaps taken apart and reassembled, as a means of becoming familiar with the structural features of the heart. The types of educational supports and activities used in everyday science classrooms often rely on such *physical models* (e.g., ball-and-stick chemical molecules; a globe of the Earth; mechanical models of engines built with Lego bricks; and gears). There are, though, other types of models that have proven valuable as educational tools. *Virtual models* are computer reproductions of actual objects (e.g., a three-dimensional image of a brain; a program that can explode the Earth to display the interior structure) or interactions between those objects and phenomena (e.g., the Physics Education Technology Project's simulations of the behavior of electrical circuits) that are manipulated through a software interface. Notably, virtual models are useful for exploring concepts or processes, but do not necessarily allow a learner to modify or iterate the underlying computer program or architecture. In contrast, *computational models* are glass-box simulations of scientific phenomena which can be modified, extended, and rebuilt by learners through direct manipulation of their underlying programs. Computational models have been designed for research domains including physics (e.g., electrical conduction), biology (e.g., natural selection), chemistry (e.g., gas laws), and materials science (e.g., crystallization) (as examples, developed in a variety of modeling platforms). These models allow individuals to design and test aspects of their simulated objects and processes, and have been used successfully as learning environments in K-16 settings. It should be noted that these various models are also employed by scientists in actual research laboratories, and thus are not restricted in terms of who might benefit from their usage.

Theoretical Background

The physical, virtual, and computational models that are employed in science classrooms and laboratories are intended as supports for helping individuals to build their own internalized *mental models* for scientific concepts. Mental models are mental representations for objects and concepts we learn and know about. For example, an experienced Earth Scientist will most likely have an elaborate understanding of the causes and consequences of earthquakes, such that predictions could be made about the likelihood of tectonic events under various geological circumstances. When individuals run mental simulations in their minds for how and why things might happen, they are employing mental models. Mental models, then, are crucial memory representations that can exemplify adequate comprehension. They are the mental products that hopefully result from the use of scientific models and other kinds of life experiences.

In the context of science education, modeling refers to the process of constructing, extending, verifying, or testing scientific models. As Schwartz and White (2005) clarify, the term *scientific modeling* identifies the process used in much of modern science that involves (a) embodying key aspects of theory and data into a model – frequently a computer model, (b) evaluating that model using criteria such as accuracy and consistency, and (c) revising that model to accommodate new theoretical ideas or empirical findings as necessary. Consider that one of the central pedagogical goals of modeling is to scaffold students' development of mechanistic explanations of scientific phenomena. In pursuit of this goal, scientific modeling requires that individuals define and identify important variables and their characteristics as pertaining to the object, system, or phenomenon being modeled. Based on these definitions, individuals can think about how the identified variables interact, and as such, how measurement of those variables and the overall model might be constructed. The success or failures of the resulting models as adequate tools for generating hypotheses and testing data-driven outcomes can be utilized in an iterative way to consider their effective redesign. Scientific modeling, then, is an iterative design process that encourages conceptual understanding and careful testing of model-relevant topics. It is worth noting that the activities described here are directly in line with the activities associated with the scientific method in general; as such, it might be argued that models are themselves the actual language of science (e.g., Giere 1988).

But beyond theoretical considerations, there is considerable evidence that scientific models and the process of scientific modeling are effective tools for learning. For example, researchers have contended that engaging in the modeling process can help individuals develop sophisticated mental models of scientific phenomenon as well as deep domain knowledge. For example, students who utilized lab-based simulations of ground-water flow demonstrated better understanding of underlying scientific principles (e.g., Darcy's law) as compared to students who were provided with texts conveying the same conceptual information (Renshaw et al. 1998). In another example, students who used computational models of electrical conduction demonstrated a much better understanding of key concepts in electricity, as compared to students who underwent traditional textbook-based instruction (Sengupta and Wilensky 2009).

Important Scientific Research and Open Questions

But what makes modeling so effective as an educational practice? Researchers have argued that computer modeling can make scientific material more accessible and interesting by bootstrapping students' personal and intuitive knowledge, as well as their naïve representational competencies. Beyond issues of motivation and engagement, researchers have also argued that models embed activities in contexts that are highly *authentic* – that is, the activities involved in scientific modeling closely align with researchers' actual practices of doing and thinking about science (Lehrer and Shauble 2000). Thus, students who engage in modeling are involved in scientific activities that necessitate causal reasoning, hypothesis testing, the generation and evaluation of ideas, and the representation, recording, and analysis of data through scientific inscriptions. These activities encourage encoding into memory, deeper processing, and the types of cognitive experiences that foster learning and transfer (Rapp and Kurby 2008).

Over the past decade or so, several new forms of modeling have emerged in science education; these models incorporate aspects of physical, virtual, and computational models in their design and usage. Some notable examples include emergent modeling, microbehavior-based modeling, tangible programming, and hybrid modeling. Emergent models are best suited for modeling complex systems, in which complex phenomena at one level (e.g., population dynamics in ecosystems; behavior of electrical circuits) emerge from simple interactions between thousands (or hundreds of thousands) of individual level actors or "agents" (e.g., predators and prey; electrons and ions), without a key leader or a centralized process. Micro-behavior-based modeling is an even more recent invention – it provides students with a few prototypical "agents" and their "behaviors." Micro-behaviors themselves are bits of code that are carefully designed to be easily understood, composed, and parameterized. Students assemble and execute combinations of these micro-behaviors to generate a composite model. Tangible programming combines the power of traditional computational programming with the usability of simple physical manipulatives (e.g., wooden blocks). Tangible programming has been used successfully in informal settings (e.g., museums) for science education. Finally, hybrid or bifocal modeling involves connecting real-world sensors and physical devices (e.g., motors) to computational models. Using such models, students can control, validate, and refine their computational models with real-world data. As these descriptions suggest, contemporary modeling trends are affording the opportunity to consider processes, phenomena, and objects that are multidimensional and complex, which without modeling would be difficult to observe and challenging to understand.

There are a variety of directions one could envision for the future of scientific modeling, but here discussion is constrained to three important elements. First, there is still a need for data on the ways in which modeling practices influence learning. This could involve projects that range from, but not limited to, ethnographic analyses of classrooms that utilize modeling as a primary or complementary instructional tool, randomized controlled trials of comparison classrooms utilizing different types of modeling scenarios and tasks, and mixed-method designs that seek to describe and explain any potential benefits (and limitations) of modeling activities. Second, future work should examine how to best prepare students for engaging in modeling practices. For example, researchers are now investigating various approaches through which students can be introduced to emergent modeling in specified STEM (i.e., science, technology, engineering, and mathematics) domains including physics, chemistry, biology, materials science, etc. Third, there is a genuine need for preparing teachers to employ modeling activities in their classrooms. This includes not just informing instructors about the available tools and models that they might use as part of their instructional activities; it also involves investigation of the challenges that students and teachers face while engaged in modeling, as well as the design of useful instructional supports that promote effective interactions by students and teachers with scientific modeling.

Cross-References

► Dynamic Modeling and Analogies
► Mental Models
► Problem-Based Learning
► Simulation and Learning: The Role of Mental Models
► Simulation-Based Learning

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Models of Latent State-Trait Theory

Models of latent state-trait-theory are psychometric models that allow measuring latent variables that represent the influence of components characterizing (a) the person, (b) the situation and/or the interaction between the person and the situation, and (c) measurement error.

Models of Measurement of Persons in Situations

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Synonyms

Latent state-trait models; Trait-state-error models

Definition

Models of measurement of persons in situations are psychometric models that allow measuring latent variables that represent the influence of components characterizing (a) the person, (b) the situation and/or the interaction between the person and the situation, and (c) measurement error. These models are often called latent state-trait models or trait-state-error models.

Theoretical Background

Many theoretical approaches propose that the behavior and the experiences of an individual depend on the person, the situation, and the interaction between the person and the situation. Examples are Lewin's (1935) dynamic theory of personality, modern interactionism (Magnusson and Stattin 1998), and Mischel and Shoda's (1995) cognitive-affective processing model of personality. According to these theories, situational influences are omnipresent. They are not only important for variable constructs such as emotions but also for traits and abilities such as intelligence. For example, the result of an intelligence test also depends on the situation the person is in on an occasion of measurement (nervousness, test anxiety).

There are many different concepts of situations. Situations can be considered as settings that are characterized by objective features such as the number of individuals present or the temperature. However, for the behavior and the feelings of an individual it is more important in which way individuals perceive and appraise specific situations. Moreover, the inner state of an individual (e.g., the current mood) can be considered as a part of the situation ("inner situation"). Therefore, the term situation often refers to the totality of all outer and inner conditions an individual is in on a specific occasion. For the measurement of individuals in specific situations, it is important to develop specific psychometric models that are able to distinguish between personal and situational determinants of behavior and experiences, that make the measurement of these determinants possible, and that allow to estimate the degree to which interindividual differences on an occasion of measurement are due to the different sources (person, situation, interaction).

Latent State-Trait Theory

Latent state-trait (LST) theory is an extension of classical test theory that allows considering situational influences (Steyer et al. 1999). In LST theory, the starting point is an observed variable Y_{ik} representing the individual scores of a measure i (e.g., intelligence test) measured on measurement occasion k. An observed variable Y_{ik} is decomposed into a latent state variable S_{ik} and an error variable E_{ik}:

$$\text{Observed variable } Y_{ik} = \text{latent state variable } S_{ik} + \text{measurement error variable } E_{ik}$$

The values of the observed variable are the observed test scores. The latent state variable characterizes an individual in a specific situation on an occasion of measurement. The values of the latent state variable are the true (error-free) state values. The latent state variable is further decomposed into a latent trait variable T_{ik} and a latent occasion-specific variable:

$$\text{Latent state variable } S_{ik} = \text{latent trait variable } T_{ik} + \text{occasions-specific variable } O_{ik}$$

The latent trait variable characterizes an individual across different situations. The occasion-specific variable is a latent residual variable. It represents the deviations of the latent state values from the values predicted by the latent traits. Hence, it is that part of a state variable that is not due to the trait variable. This part comprises the influences due to the situations the individuals are in on an occasion of measurement and/or the interaction between the individuals and the situations. The influences due to the interactions cannot be separated from the influences due to the situations because in natural life, the persons and the situations are not independent from each other and – according to the concept of inner situations – the situations are often not known. If specific aspects of the situations are measured, these aspects can be included in the model as occasions-specific covariates.

Variance Components

In LST theory, the variance of an observed variable can be decomposed into the variance of the latent state variable and the variance of the error variable:

$$\mathrm{Var}(Y_{ik}) = \mathrm{Var}(S_{ik}) + \mathrm{Var}(E_{ik})$$

The part of the variance of the observed variable that is due to the latent state variable is the *reliability* coefficient. It is the percentage of variance of the observed variable that is not due to measurement error:

$$\mathrm{Rel}(Y_{ik}) = \mathrm{Var}(S_{ik})/\mathrm{Var}(Y_{ik})$$

The variance of the latent state variable can be further decomposed into the variance that is due to the trait variable and the variance that is determined by the occasion-specific variable:

$$\mathrm{Var}(S_{ik}) = \mathrm{Var}(T_{ik}) + \mathrm{Var}(O_{ik})$$

The *consistency* coefficient is the variance due to the latent trait variable divided by the variance of the observed variable:

$$\mathrm{Con}(Y_{ik}) = \mathrm{Var}(T_{ik})/\mathrm{Var}(Y_{ik})$$

It shows to which degree observed interindividual differences on an occasion of measurement are due to stable individual differences. The *occasion-specificity* coefficient is the variance that is due to the occasion-specific variable divided by the variance of the observed variable:

$$\mathrm{Spe}(Y_{ik}) = \mathrm{Var}(O_{ik})/\mathrm{Var}(Y_{ik})$$

It indicates to which degree observed individual differences are due to occasion-specific influences (situations, interactions). These coefficients can be used to evaluate the appropriateness of a psychological test to measure stable (consistency) or variable (specificity) constructs. For example, a test measuring stable abilities should show high consistency coefficients whereas a questionnaire measuring variable mood should show high specificity coefficients.

Models of Latent State-Trait Theory

In LST theory, an observed variable is decomposed into different components that are not observable. If one considers only one observed variable, it is not possible to measure the latent variables because there is not enough information in the data. In order to measure the latent trait and the latent occasion-specific variables and to estimate the different components of variance, psychometric models with more than one observed variables are needed. It is necessary to have at least two occasions of measurement and two indicators that measure the same construct on each occasion of measurement. That means that it is obligatory to have at least four observed variables. Moreover, these observed variables have to follow specific assumptions. These assumptions differ between different models of LST theory. Models of LST theory are described by Steyer et al. (1999). In the simplest model of LST theory, it is assumed that all observed variables on the same measurement occasion measure the same latent state variable, and that all latent state variables measure the same latent trait variable. Besides models of LST theory, there are related models that are based on very similar ideas, for example, trait-state-error models presented by Kenny and Zautra (2001). LST models for categorical observed variables are described by Eid and Hoffmann (1998).

Important Scientific Research and Open Questions

Models of LST theory have been successfully applied in many different areas of psychology to assess the reliability, consistency, and specificity of the measures considered. For example, Eid and Hoffmann (1998) have analyzed how stable and variable interests in physics are, and they could show that there was a change in the trait component of interests in physics after the Chernobyl disaster. Hagemann et al. (2005) have applied models of LST theory to analyze resting EEG asymmetry. Kirschbaum et al. (1990) have analyzed salivary cortisol levels with LST models. There are many different applications to the measurement of mood, emotions, and attitudes (for an overview see Steyer et al. 1999). In most cases, situational covariates have not been entered into the model. This might be partly due to the fact that comprehensive theories of situations are missing that could guide the measurement of characteristics of the situation. Future research should focus more strongly on the measurement of situational features that should be included in these models.

Cross-References

► Measurement of Change in Learning
► Situated Cognition
► Situated Learning

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Modern Apprenticeship

► Learning in Practice and by Experience

Monitoring Affective Trajectories During Complex Learning

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Synonyms

Affect dynamics; Affect transitions; Affect sequencing

Definition

An affective state is a feeling, mood, or emotion. Students' experience affective states during learning activities such as problem solving, studying for an exam, taking a test, or learning from a human or computer tutor. An affective trajectory is a sequential pattern of affective states that change over time. For example, confusion followed by frustration followed by anger is an affective trajectory. Complex learning pertains to learning at deeper levels of comprehension. Complex learning requires learners to generate inferences, answer causal questions, diagnose and solve problems, make conceptual comparisons, generate coherent explanations, and demonstrate application and transfer of acquired knowledge. This form of deep learning can be contrasted with shallow learning activities, such as memorizing key phrases, definitions, and facts, and classical associative learning. This entry is concerned with tracking sequences of student affect during complex learning activities.

Theoretical Background

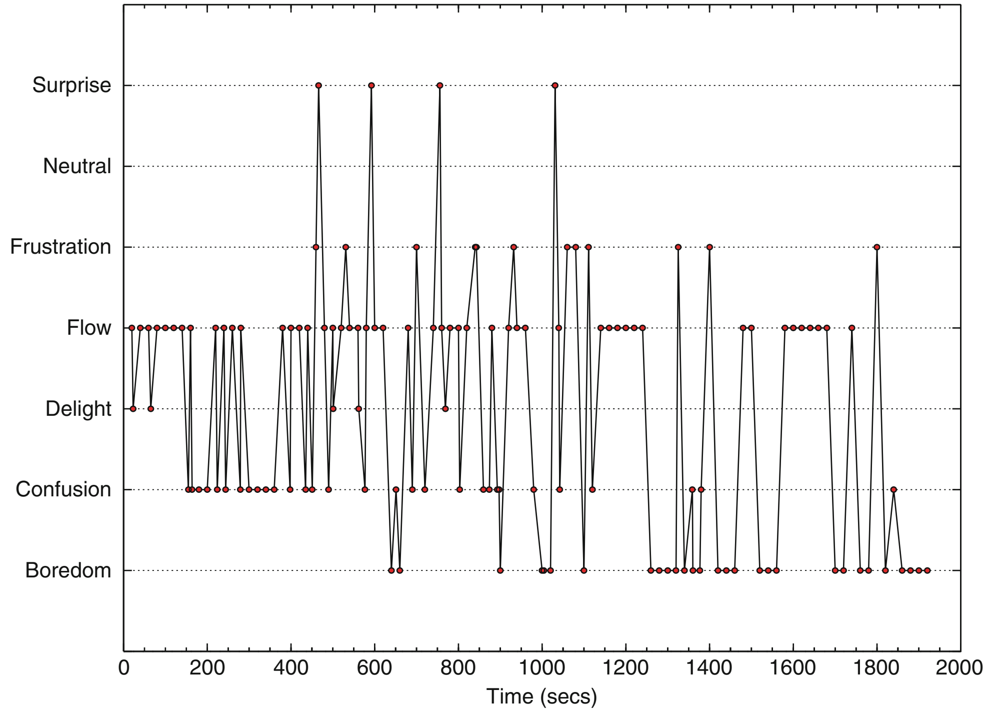
Efforts to learn difficult subject matter at deeper levels of comprehension (i.e., complex learning) involve a complex coordination of cognitive and affective processes. Cognitive processes such as diagnosing problems, making salient comparisons, and generating explanations are inevitably accompanied by negative emotions such as confusion, frustration, anger, and sometimes rage when the learner makes mistakes, struggles with troublesome problems, gets stuck, and experiences failure. On the other hand, positive emotions such as flow, delight, excitement, and eureka are experienced when tasks are completed, challenges are conquered, insights are unveiled, and major discoveries are made.

Theoretical frameworks that predict systematic relationships between affective and cognitive processes during learning are beginning to emerge in the fields of psychology (Dweck 2002), education (Schultz and Pekrun 2007), neuroscience (Immordino-Yang and Damasio 2007), and artificial intelligence (Conati and Maclaren 2009). Some of the emerging theories that link affect and learning have highlighted the importance of confusion, frustration, boredom, flow/engagement, anxiety, curiosity, delight, and surprise to learning activities. Although identifying the emotions that are relevant to learning is an important step, knowing *what* states occur and how they impact learning does not tell the entire story. What is missing is a specification of *how* these states *evolve*, *morph*, *interact*, and *influence* learning and engagement.

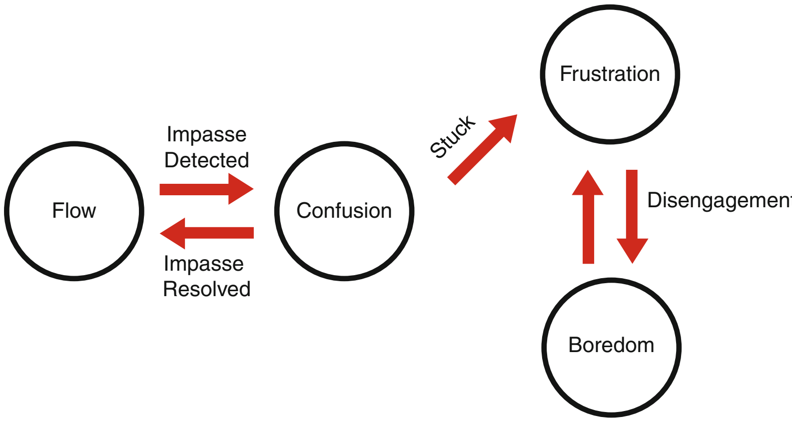
An analysis of the affective trajectories is particularly relevant because emotions are seldom static and persistent; instead, they are dynamic and highly transient. For example, consider the affective trajectory of an actual learner from a learning session with a computer tutor (see Fig. 1). The learner settles into the flow or engaged state after initially oscillating between engagement and delight. An *impasse* potentially causes the learner to transition out of the engaged state into a state of confusion. Repetitive oscillations between confusion and flow are observed, presumably as problem solving proceeds. Sometimes the learner gets stuck and experiences frustration. Success in problem solving yields delight and extreme novelty triggers surprise. This is the dominant pattern of affective transitions until boredom emerges toward the end of the session.

A model of *cognitive disequilibrium* is one framework to understand the affective transitions that emerge during learning. The model postulates an important role for cognitive disequilibrium in comprehension and learning processes. Cognitive disequilibrium is a state that occurs when learners face obstacles to goals, contradictions, incongruities, anomalies, uncertainty, and salient contrasts (Piaget 1952). Cognitive equilibrium is restored with thought, reflection, problem solving, and other effortful deliberations. The model states that the complex interplay between external events that trigger impasses, and the resultant cognitive disequilibrium, are the key to understanding the dynamics of the affective processes that underlie learning.

The model suggests that learners who are in a flow/engaged state will experience confusion when an impasse is detected. They engage in effortful problem solving activities in order to resolve the impasse and restore equilibrium. Equilibrium is restored when the impasse is resolved and learners revert back into the flow/engaged state. However, confusion transitions into frustration when the impasse cannot be resolved, the student gets stuck, and important goals are blocked. Furthermore, persistent frustration may transition into



Monitoring Affective Trajectories During Complex Learning. Fig. 1 Sample affective trajectory during a learning session with a computer tutor



Monitoring Affective Trajectories During Complex Learning. Fig. 2 Transitions between affective states

boredom, a crucial point at which the student disengages from the learning process. Boredom may revert back into frustration when a student is forced to endure the session despite his or her ennui.

Emerging evidence has confirmed the presence of confusion – flow and boredom – frustration oscillations as well as confusion to frustration transitions (see Fig. 2) (D'Mello and Graesser 2010). Hence, students in the state of engagement/flow are continuously being challenged and are experiencing two-step episodes alternating between confusion and insight. In contrast to these *beneficial* flow–confusion–flow cycles, there are the *harmful* oscillations between boredom and frustration. As the cognitive disequilibrium model asserts, confusion plays a central role in the learning process because it the gateway to positive (flow) and negative (frustration) emotions.

Important Scientific Research and Open Questions

At this point in science, we have only begun to understand the dynamics of student emotions during learning. The present entry has described an emotional trajectory that was observed (and replicated) in *one* learning context. There is the important question of whether this trajectory replicates across different learning environments (human tutors, computer tutors, classrooms), topics (science vs. math), and learner populations (ages, cultures, etc.). If the major patterns in Fig. 2 generalize to different contexts, then we will have some confidence that the cognitive disequilibrium model is a viable framework to study affect dynamics. However, failure to replicate the patterns will be equally informative, because it would highlight the need for either a more comprehensive model that generalizes across contexts, or individual models that are sensitive to subtle nuances in contexts.

There are also opportunities for the model to be refined and expanded. Currently, transitions from one state to another are governed by single links (e.g., impasse detected). This leaves room for additional possibilities. For example, identifying multiple conditions that trigger transitions between the same pairs of states would represent one important advance. The model can also be expanded in scope as it currently only addresses four affective states. Expanding the model to include additional learning-relevant affective states such as anxiety and curiosity would be another item for future research. It is also unlikely that all learners transition through emotions in similar ways. Hence, refining the model to incorporate individual differences in prior knowledge, ability, motivation, and learning styles is yet another crucial and open problem. Finally, in addition to these research questions that attempt to provide a *process level* account of the affective trajectories during learning, there is also a need to understand how affective dynamics influence the *products of learning* (i.e., distinguishing transitions that facilitate learning from transitions that hinder learning).

Cross-References

► Affective and Cognitive Learning in the Online Classroom
► Affective Dimensions of Learning
► Boredom of Learning

► Cognitive and Affective Learning Strategies
► Confusion's Impact on Learning
► Emotion-Based Learning
► Emotions: Functions and Effects on Learning
► Flow Experience and Learning

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Monoaminergic Drug

► Amphetamine, Arousal, and Learning

Monotony

► Boredom in Learning

Monte Carlo Tree Search

► Learning with Monte Carlo Methods

Mood

► Affective and Emotional Dispositions of/for Learning
► Emotional Intelligence in Animals

Mood and Learning

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Synonyms

Affect

Definition

Mood is understood as a momentary, relatively long lasting, and subjectively experienced state of mind, the cause of which is generally unclear. Unlike emotions, mood states are generally less specific and less likely to be triggered by a particular environmental or intrapsychic stimulus. Moreover, the low mood intensity does not normally interrupt current actions and behavior. Mood can be described as a continuum ranging from a bad/negative to a good/positive mood. People generally state that they are in a good or bad mood. Note that even if from an experimental and methodological point of view, good and bad moods are distinguished from a neutral mood, everyday experience and experimental analyses show that people are generally in a good mood. One major function of mood is to inform the subject about the general quality of her or his momentary emotional state. When the diffuse state of mind goes below or exceeds a certain intensity, duration, and characteristics, these mood states are generally regarded as pathological. An exceedingly good mood may lead to hypomania and mania, whereas an exceedingly bad mood may lead to dysphoria and a depressive disorder.

With regard to the association between mood and learning, there is a general consensus that mood influences learning, that is to say: mood may change the way information is processed cognitively. By contrast, no general consensus is observable with regard to the manner in which a specific quality of mood (good vs. bad) may have a favorable or unfavorable influence on cognitive processes (see below).

Theoretical Background

Research on mood and learning focuses on the influence of both positive and negative mood states on learning performance and cognitive processes.

To explain why different mood states may have a favorable or unfavorable influence on the processing of information, research has focused on the reduction of the information processing capacity. Accordingly, it has been argued that a positive mood leads to a depletion of central executive processes, because the person is occupied with finding out why he or she is in that specific mood state. As a result, less cognitive capacity is available for the processing of the learning tasks. By contrast, at least four reasons have been offered for the fact that a negative mood is associated with a reduction in cognitive performance, again, all of them focusing on the reduction of the information processing capacity. First, the resource allocation model (Ellis and Ashbrook 1988) points out that people in a sad mood are concerned with extra-task processing (e.g., thinking about their own bad mood) or with task-irrelevant processing. Second, a bad mood leads to a depletion of central executive processes. Third, a bad mood leads to a reduction of the information processing capacity since subjects in a bad mood are more concerned with finding the reason for their specific mood than with solving the task at hand. Fourth, Alice Isen (1987) proposes that a person in a negative mood tries to regain a better mood ("*mood repair*"); as a consequence, cognitive capacity must be divided between the task and the mood correction.

Why should a positive mood lead to improved cognitive performance? The underlying theoretical framework is based on the idea that subjects in a positive mood may have access to more varied information. Consequently, there is a tendency to see a relationship between types of information that are normally not associated. This suggests that a good mood influences the breadth of attention, thus resulting in a larger and more varied range of information. A neurobiological theory of positive affect points out that a positive mood may be directly associated with increased dopamine levels in the brain.

Important Scientific Research and Open Questions

With regard to the specific direction of the relation between mood and performance, there does not seem to be one general rule. There is empirical evidence that cognitive performance may be reduced in the presence of a positive, as opposed to a negative mood. These findings tally with models assuming that a positive mood leads to a simplification of cognitive processes, a reduction in processing capacity, and a decline in motivation. In particular, it is argued that a positive mood suppresses convergent, analytic thinking by depleting central executive resources while solving, for instance, the Tower of London problem. Additionally, with respect to social perception, people in a positive mood are more prone to rely on stereotypes and are more vulnerable to halo effects. These observations are in agreement with the claim that a positive mood impairs performance. By contrast, a number of studies demonstrate that a negative mood can result in more systematic, elaborate, and analytical cognitive processing, and can significantly reduce halo effects. People in a negative mood (as compared to those in a neutral or positive mood) seem especially likely to engage in systematic processing, to adhere more consistently to the given data and to show less confidence in their assumptions. Correspondingly, judgments of people in a negative mood are less influenced by stereotypes, and more specifically by negative stereotypes. As recent data suggest, a negative mood induced by bad weather even leads shoppers to show increased memory performance for unusual objects placed in the check-out area (Forgas et al. 2009). Yet the observation that a negative mood may improve performance is at odds with the conclusion that a bad mood is associated with a reduction in cognitive processing.

Improved performance has been observed in subjects in a positive mood when a task requires either elaboration of the given data, decision making, logical thinking, problem solving, transfer of problem-solving procedures, or broadening the scope of attention (see Brand et al. 2007 Isbell 2003; Isen 1987). Furthermore, it has been shown that people in a positive mood were more likely to acquire a problem-solving procedure. In addition, an increased flexibility in thinking has been found to co-occur with a positive mood: subjects in a positive mood solved insight problems or word association problems faster and more accurately than subjects in a negative mood. Furthermore, subjects in a positive mood showed flexible thinking even when they were not required to do so. Recent research has emphasized the concept of affect-as-information (the AAI-model; see Martin and Clore 2001) according to which the assessment and significance of the momentary situation and hence also the associated processing style changes as a function of mood. If situations are interpreted as being unproblematic and not requiring caution, it can be assumed that the already existing knowledge structures can be used successfully and repeatedly. On the other hand, unknown or problematic situations require a more information-driven procedure. Thus, people in a positive mood should have confidence in their available cognitive concepts, whereas those in a negative mood tend to take the existing data into account and engage in more systematic information processing.

In sum, the empirical findings are controversial; a positive mood can be associated with reduced cognitive performance but also with more flexible thinking; a negative mood can result in more systematic and data-oriented information processing but can also impair performance.

Cross-References

► Capacity Limitations of Memory and Learning
► Cognitive Learning
► Creativity, Problem Solving, and Feeling
► Mood-Dependent Learning

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Mood Congruency Learning

► Emotion-Based Machine Learning

Mood-Congruency

► Mood-Dependent Learning

Mood-Dependent Learning

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Synonyms

Mood-congruency; State-dependency

Definition

Mood is understood as a momentary, relatively long lasting, and subjectively experienced state of mind, the cause of which is generally disregarded. Unlike emotions, mood states are generally less specific and less likely to be triggered by a particular environmental or intrapsychic stimulus. Moreover, the low mood intensity does not normally interrupt current actions and behavior. Mood and learning performance are associated (see *Mood and Learning*). Here, we focus on the influence of mood during the encoding and retrieval of knowledge.

Theoretical Background

The acquisition of knowledge is not an exclusively cognitive process; rather, affective and emotional states continuously co-occur during learning processes; accordingly, there is compelling evidence that during the encoding, storage, and retrieval of knowledge affective information is also encoded, stored, and retrieved. Note that learning refers to both explicit and implicit learning processes, whereby explicit learning processes refer to the conscious and intentional acquisition of knowledge, and implicit learning processes refer to the unconscious and unintentional acquisition of knowledge. In this respect, implicit learning processes occur, when the learning performance is related to mood states.

Example 1: A high school student has to learn 50 new French words. She is in a good mood, because she is looking forward to playing tennis afterwards. First, it is highly conceivable that these 50 new French words are associated with a good mood, that is, implicitly, the knowledge acquisition (encoding 50 new French words) is closely connected with a good mood. Second, following Bower's (1981) concept of *state-dependent learning*, the student will perform the test well, when she is in a good mood during the test, whereas she will perform less well, when she is in a bad mood during the test. In other words: the mood (in this case: good mood) during the encoding and retrieval stages is identical, and therefore, the knowledge acquired in this mood state is much better retrieved. As a result, learning performance is increased.

Example 2: The high school student has to study a chapter in history related to the millions of innocent civil victims during World War II. Specifically, she is learning how ruthless squadrons killed innocent children and defenseless women. Thus, the content of what has to be learned is associated with the affective value of sadness, grief, and consternation. How does her learning performance change as a function of the mood during retrieval? Bower's concept of *mood-congruency* (1981) would predict an increased learning performance if the high school student is in a bad mood (i.e., the current sad mood tallies with the sad content of what has to be learned). By contrast, the concept of *mood-congruency* predicts a decreased learning performance if the high school student is in a current good mood, because the affective value of the learning matter is not congruent with the current mood.

Important Scientific Research and Open Questions

Bower and Mayer (1985) observed that their predictions did not match the data entirely. Specifically, whereas participants in a good mood did show an increased performance remembering information with a positive affective value (*mood-congruency*), this was not the case for participants in a bad mood: these participants did not show an increased learning performance remembering information with a negative affective value. How do we explain this asymmetry? Isen (1987) postulates that people in a sad mood are inclined to shift their mood from a bad mood to a good mood (*mood repair)*. Therefore, while changing the quality of mood during the test phase, participants also alter the associations between their mood and the affective value of the learning material. Bower and colleagues acknowledged that processes of state-dependency and mood-congruency could not be systematically replicated; rather, effects of state-dependency and mood-congruency are observed if the learning material is of high individual and personal affective value (i.e., the content of the learning material triggers personal current concerns).

Whereas research in cognitive psychology showed that the association between mood and learning is not as simple as suggested by the concepts of state-dependency and mood-congruency (see *Mood and Learning*), in cognitive-behavioral therapy the two concepts have gained importance to the extent that, as a rule of thumb, patients are motivated to shift their mood from a bad mood to a good mood. In so doing, first, the recall of negatively affected memories should be reduced (*state-dependency*), and second, the therapeutic (working and) progress should be associated with a positive mood (*mood-congruency*).

Cross-References

► Emotion Regulation
► Emotions in Cognitive Conflicts
► Mood and Learning
► Stress Management

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Mood-Dependent Memory

Mood-dependent memory occurs when the congruence of current mood with the mood at the time of memory storage helps to recall stored information of the past. For instance, when people are happy, they are more likely to remember other times when they were happy.

Moore's Law

Moore's law describes the long-term trend between 1970 and 2010 in the history of computing hardware. This law states that the number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every 2 years.

Moral Development

► Moral Learning
► Video Games for Prosocial Learning

Moral Education

A theory of prosocial development based on work by Piaget and Kohlberg that asserts individuals can deepen their moral reasoning skills through both experience and education.

Cross-References

► Moral Learning

Moral Engagement

► Video Games for Prosocial Learning

Moral Internalization

► Prosocial Learning in Adolescence: The Mediating Role of Prosocial Values

Moral Learning

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Synonyms

Character education; Ethics learning; Moral development; Moral education; Moral socialization; Values education

Definition

The topic of moral learning and development is every type of acquisition of morally or ethically relevant dispositions (values dispositions), namely, spontaneous learning and development, socialization, and moral and values education. Morally or ethically relevant dispositions are dispositions which are concerned with a subject's values decisions, values justifications, values arguments, and moral action. Values in this context are judgments about whether something must be done or must be avoided, whether it is right and wrong, etc. Four issues seem important in this context: (1) Moral values are always values that draw on reflection, that are argued for (or against); (2) these arguments deal with questions of welfare, justice, care, and rights, or other issues that are seen as obligatory and to some degree as general regardless of a specific person's attitude toward it; (3) they are distinct from conventional values (customary practices of social systems) and personal choices (Turiel); (4) mostly moral values have also an emotional component, with feelings like guilt or good or sore conscience. One can distinguish two types of values dispositions, namely, (1) content dispositions: *What* values are defended by the subject (such as life, tolerance, property), and (2) judgment dispositions: *How* values are defended by the subject (such as by referring to universal principles or to the law or by obedience). The content dispositions are usually discussed within moral learning while the judgment disposition is the topic of moral development (Kohlberg 1981/1984).

Theoretical Background

One can assume that some values dispositions (such as altruism) and some prerequisites for morality (capacity for empathy) have phylogenetic roots but are shaped through experience. Most of them, however, are acquired during lifetime. Learning and development in the moral domain will happen in any case: If not intentionally and goal-directed guided by another person or a curriculum effort (manifest education) it will be an unconscious process of moral learning (latent education) which is unsystematic and incidental or a developmental process in which maturation and socialization influences interact.

Many models of moral learning, development, and socialization have been proposed, among which the following are seen as the most important by the authors:

1. Cognitive social learning theory
2. Socialization
3. Development through values clarification
4. Development of the moral judgment (Kohlberg 1981/1984)

These approaches must not be seen as independent, but as complementary. The first three focus primarily on content dispositions, whereas the last addresses judgment dispositions.

The *cognitive social learning theory* (Bandura, Mischel) refers to learning that is triggered by social interactions. This includes, but is not restricted to, reinforcement, punishment, and imitation. While it has its origins in behaviorism, it is now a cognitive approach, focusing, among others, on cognitive variables like the person's perception of the situation and expectations, goals, and self-regulation in specific situations. Morality is important in two regards: (1) Values (in the sense of goals in particular situations) play an important role ("what is important to me?"); people have several goals simultaneously (in the same situation), which might be in competition with each other, and some of these goals or values are morally justified, some are not. For instance in a particular situation morally justified values may push the protagonist to do one thing but personal priorities may push to do the opposite; what the protagonist then actually does will depend on the weights of the different goals. (2) Values are acquired (internalized) through cognitive social learning processes: Positive and negative sanctions – whether intentionally set by educators or a natural consequence – following an action which is identified as moral (according to the definition above) and modeling moral behavior may have an influence on the values a person defends. One important issue is whether the person pays attention to the moral dimension of the action under consideration. In any case, it is the person who decides whether to internalize such a value or not. There are several further processes that can be included, such as discipline strategies, power assertion, love withdrawal, and reasoning from the part of social agents and the protagonist's anger, feeling of guilt, etc. (Hoffman 1975).

Socialization is closely related with cognitive social learning. Socialization theory deals with understanding the continuity of values from generation to generation and the processes of values transmission, including the bilateral internalization (e.g., influence of the children on their parents). However, society develops, and the diversity of values within cultural groups has strongly increased over about half a century; as a corollary, values will change from generation to generation due to differing social and technological conditions, to the introduction of new ideas in the society (e.g., postmodernism), social processes like multiculturalization, individualization, and secularization, to changed priorities, etc. Besides parents, other adults and institutions as well as peers have influences on the children and are, in turn, influenced by them. Again, as in cognitive social learning, children are perceived as actively internalizing the values in what Kuczynski and Navara (2006) call the child's "personal working model" that is influenced by the parents' personal working model, but also by the working models of the child's culture and the child's generation (p. 312 ff.); this influence works through the child's committed (voluntary or even enthusiastic) compliance with the proposed values, compliance due to external pressure, unwilling compliance (children show their agency by complying as little as possible or under protest), and accommodation (the child cooperates but reinterprets the way of compliance). It is also possible that children reject the values that are offered (noncompliance). This means also that the values system of a person is in constant development (Kuczynski and Navara 2006).

The theory of *values clarification* (Raths et al. 1966) is an educational concept. The assumption is that through focusing the children's attention on issues of their lives and stimulating them to consider their choices, etc., they will acquire morally relevant dispositions like values awareness. The teacher's role is only one of a facilitator, and there is no attempt to influence except for extreme concepts; within these limits, whatever values the child defends have to be accepted and respected. The underlying learning model is important which stipulates that children are confused by the multitude of values and the values conflicts they experience. Reflection on life experience and values would then help them to be more self-directing and so to overcome the values confusion, to know what they really value – and what not. Raths et al. developed a series of techniques to achieve this goal; however, evaluations showed that the program did not achieve the goals that were set.

Kohlberg's (1981/1984) theory of *moral judgment* and its *development* is a constructivist approach. "Judgment" means here how people justify the moral choices they make in a given situation (typically a dilemma situation); hence it focuses on the arguments people use (see issue (1) in the definition above). Kohlberg distinguished six developmental stages of moral judgments: (1) obedience and submission, (2) mutual interests and exchange, (3) adherence to reference group, (4) maintaining social order, (5) social contract and individual rights, and (6) universal principles. Research in the Kohlbergian tradition showed that the individual development progresses in this sequential order, that there are no regressions, that persons arguing on a certain stage usually understand arguments on the next higher stage and reject arguments on lower stages, and these results tend to be independent of the culture. Not all people reach the highest stage; rather most of them stay on stages 3 and 4, which are called "conventional," whereas only few reach the "post-conventional" stages 5 and 6. The development can be explained according to Piaget's equilibration model: When confronted with a problem he or she cannot solve with the existing cognitive structure, a person "invents" a new way to argue (accommodation in the sense of Piaget); this new argumentation pattern will be on a higher stage. The process needs weeks or even months and repeated challenges (unsolved problems). For education purposes dilemma discussions are used: The subjects are confronted with a situation whose protagonist has to take a decision; whatever he or she decides, an essential value will be broken. The subjects discuss and argue in favor or against the different values and mutually challenge their justifications with arguments they believe to be better. While Kohlberg focused on justice, other authors in this tradition had other priorities (e.g., care is addressed by Gilligan; see issue (2) in the definition above).

Important Scientific Research and Open Questions

A central issue in the field of moral learning and development is the normative background. Morality can be seen from a descriptive standpoint: How are values learned, how does moral argumentation develop, etc. But it must also be seen from an ethical point of view: Which values and argumentation structures are normatively required individually, in a society or for humankind (see also issue (2) above in the definition)? The relationship between descriptive and normative ethics needs to be made more explicit in research on moral learning and development. The appropriate meta-ethics is nonnaturalistic: The naturalistic fallacy (the conclusion from Is to Ought) must be avoided, and normative statements must be argued for according to the principles of normative ethics; in research and discussions on moral learning and development this distinction is often not made. For instance values clarification (see above) is criticized for being relativistic; this criticism is justified, however this is not based on descriptive statements (like "values clarification has little influence on moral learning and development") but on normative grounds since relativism is ethically inacceptable because it would permit practices that must be rejected for being inhuman.

A second challenge is the importance of emotions in regulating values and behavior. Especially the relations between moral cognitions, feelings, and expressions need further attention (see also issue (4) above in the definition).

The impact of moral competence or moral judgment on behavior is still an important issue; one can assume that features of situations (and their interpretation by the person) are important (see above, feature (1) in the cognitive social learning theory).

Moral education is important in several regards. First, the problems with values justification have already been addressed. Second, although several programs and practices in the field of moral education advocate the development of virtues and hope to shape directly and systematically the moral behavior of the new generation a lot of basic and evaluation research is needed to deliver demonstrable evidence of the effectiveness of the various character education approaches. Third, the teachers' morality needs to be discussed (Klaassen and Maslovaty 2010). Being a teacher nowadays means that one needs the courage to keep to certain professional and moral standards and to promote the development of moral norms and values in their students. Besides the braveness to do this, moral courage also points to the perseverance to stick to the goals that are oriented to the well-being of the student and the will and competence to function as a moral exemplar.

Finally, educational concepts based on the Kohlbergian framework have been quite successful. One of them, V*a*KE (Values *and* Knowledge Education, Patry et al. 2007), integrates constructivist values education and constructivist knowledge acquisition: A moral dilemma is used as challenge (in the sense of Piaget, see above) both for moral problem solving and for information search (e.g., on the Internet). Students defend their own standpoints and are challenged by their peers. The discursive debate on alternative points of view triggers the awareness of the own values and argumentation principles; on the other hand, to support the decision the students need information which they look for on the Internet. Evaluations have shown this approach to be quite effective.

While dilemma discussions and V*a*KE focus on the moral judgment, Kohlberg's Just Community approach emphasizes moral action. A Just Community is a participatory democracy (e.g., school): The members decide shared rules that govern their living together. The process of collective norm development causes a strong sense of obligation to abide by the rules and active care for the welfare of the community and each single member. As a result, the moral atmosphere (the sense of community, solidarity, and unity) is positively influenced and leads to moral actions directed by fairness.

Cross-References

► Adaptive Learning Through Variation and Selection
► Change of Values Through Learning
► Constructivist Learning
► Cooperative Learning
► Development and Learning (Overview)
► Knowledge Acquisition: Constructing Meaning from Multiple Information Sources
► Kohlberg, Lawrence
► Piaget, Jean (1896–1980)
► Socialization-Related Learning

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Moral Socialization

► Moral Learning

Motivated Forgetting

► Directed Forgetting

Motivation

► Measurement of Student Engagement in Learning
► Motivation, Learning, and Performance
► Socio-emotional Aspects of Learning

Motivation and Learning: Modern Theories

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Synonyms

Conation; Drive; Goal; Need; Purpose; Volition

Definition

Motivation is a process of interaction between the learner and the environment, which is marked by selection, initiation, increase, or persistence of goal-directed behavior. It has been thought of variously as a quality of the individual, the situation, or the activity in which the individual is engaged.

Theoretical Background

In the broadest sense, motivation is used to explain the increase or decrease in the frequency and/or intensity of an individual's goal-seeking behavior. It has been described as both a quality of an individual and a result of the individual's interactions with the situation. As an individual trait, we describe a person as being motivated, implying that the force behind behavior change is within the individual regardless of the situation. As a characteristic of the situation, we describe circumstances as being motivating, implying that it is the conditions under which a person is performing that provide the impetus for behavior change without the individual's intervention. More recently, research has focused on interactions between the individual and the environment as the impetus for behavior change.

Research and theory on motivation have moved away from a model based on a deficit of some desired situation (e.g., drive theory was based on a deficit in the physiological balance of the individual; needs theories were based on deficits in the psychological/social balance of the individual) to a model that stresses the way the individual interprets the situation. Thus unlike early theories which were more mechanistic, modern theories acknowledge that what is motivating to one individual might not be to another. Older theories have not been replaced entirely by cognition-based theories, however. Deficits still have their place in motivational analysis, just not as prominently or reliably.

Of current theories, the ones that have been the most helpful in understanding motivation are (1) attribution theory, (2) expectancy value theory, (3) self-efficacy theory, (4) achievement goal orientation theory, and (5) self-determination theory.

Attribution Theory

Attribution theory is based upon the idea that people try to explain past events by identifying the possible causes for those events (Weiner 1984). The attributions one makes then affect future motivation. Individual differences may arise in these explanations (i.e., one student may attribute failure on a test to his lack of studying, while another student may attribute failure to what he perceives as the instructor's unfair grading practices); however, all attributions fall somewhere along the following dimensions: locus, constancy, and controllability.

Locus refers to whether the cause of the event is considered internal or external to the individual. Aptitude and effort are examples of internal attributions, whereas help from others and task difficulty are external. In the previous example, attributing failure to lack of studying is an internal attribution, but blaming the teacher's perceived unfair grading practice is external.

Constancy includes the aspects of stability and consistency. Weiner explains, "Stability relates to *temporal* consistency, while globality is concerned with *cross-situational* consistency" (Weiner 1984, p. 21). In the initial example, lack of studying is an unstable attribution (the student could always choose to study more) and a teacher's grading practices are "situational" to that class only.

Controllability relates to how much control the individual believes he had over the situation. If he chose not to study, but to go out with friends, there was high controllability. If, however, he failed to study due to illness, there was low controllability. This is different from the first dimension, causality, in that all things internal are not necessarily controllable, (e.g., illness), and all things external are not necessarily uncontrollable (e.g., loud study environment can be altered).

While there is general agreement regarding where attributions fall along these dimensions, it is one's own perception of an attribution's characteristics that affects motivation. The most motivational attributions are internal, inconsistent, and controllable, because they are within one's power to change. Attributions that are external, consistent, and uncontrollable suggest one is powerless to influence the outcome. Consider the student who performs poorly on exam and attributes the outcome to lack of studying versus the one who blames the instructor for unfair grading practices. The first attribution empowers the student to change his behavior before the next exam and attain a better result, while the second leaves the final outcome in what he perceives to be the unjust hands of another.

Expectancy Value Theory

As one of the earliest motivational theories to represent a cognitive interpretation of motivation, expectancy value theory is actually a combination of two separate, but linked sources: an individual's belief that he will be able to succeed at the task (expectancy) and the degree to which the task is something that he values (value) (Eccles and Wigfield 2006). If either of these two sources is low or missing altogether, the overall effect will be to lower his motivation. So, for example, a student might be motivated to take a math course because she enjoys the content (task value) and is good at math (expectancy for success). However, if either of those two things is not true (she does not enjoy it or is not good at it), her motivation is lower.

The expectancy side of the equation can be affected by several sources. These include prior or ongoing success at the activity, a match between the learner's skills and the requirements of the task, and persuasion from a credible source, like a teacher or coach. So a student might study math because she is usually successful at it or because a respected teacher tells her that she will be successful.

The value side of the equation also has several sources, such as a match to the learner's goals, approval of the activity by the individual's social group, intrinsic interest and challenge, physiological and affective responses interpreted as pleasurable, recognition with praise and support, and some sort of tangible gain such as money or prizes. A student might study math because her future career requires it or because her peer group thinks it is a mark of intelligence to be good at math.

One can influence another's motivation by increasing either the expectancy for success or the value of the task. However, it is the interpretation of the situation by the learner that determines whether a particular action will enhance motivation. What one individual finds valuable, another might not. How one individual interprets signs of success might be different from another individual.

Self-Efficacy (cf. Self-Efficacy of Learning)

Recent developments in motivation have focused on the individual's self-control and how it is impacted by and impacts his behavior. Bandura's Social Cognitive Theory (Pintrich and Schunk 2002) is the overarching theory of learning that exemplifies this idea of reciprocity between the individual and the environment. The motivational component of this theory is referred to as self-efficacy theory. In this component, motivation stems from the individual's belief that he will be successful at a task. An important characteristic of self-efficacy is that it is task-specific rather than all encompassing. For example, an individual might have self-efficacy in the area of interpersonal relationships. This means that he believes he can interact effectively with others most of the time. As a result, his motivation to interact with others is enhanced. If he had low self-efficacy in this area, he would be more likely to avoid social situations.

Self-efficacy is developed through prior success with a task type, through observation of another person similar to the individual being successful, and through encouragement and feedback from a respected other. Self-efficacy is similar in meaning to expectancy for success in expectancy-value theory, and the competence component of self-determination theory. It might also be considered similar to having an internal locus of control for a particular situation in attribution theory. All these theories credit a belief in one's own ability as a significant source of motivation.

Self-Determination Theory (cf. Self-Determination of Learning)

The concept of intrinsic and extrinsic motivation, or doing something for the inherent satisfaction of doing it versus the rewards received from an outside source, has been extensively explored throughout motivation research but ultimately better explained by self-determination theory (Ryan and Deci 2000). Although this theory recognizes intrinsic motivation as an internally driven desire to behave in a particular way, it is unique because it differentiates between several forms of extrinsic motivation, which vary in terms of the level of self-determination involved. In the lowest form, a person who is externally regulated engages in a specific behavior to either receive a reward or avoid punishment (equivalent to extrinsic motivation). The next three forms of external regulation are referred to as introjection, identification, and integration and represent increased levels of internalizing of the external reasons for a behavior.

For example, according to this theory a student will be more motivated if he is allowed to determine his own topic for a writing assignment (intrinsic motivation). However, he will also be motivated if he chooses the topic because it is valued by society (internalized extrinsic motivation).

Like most other cognitive theories, self-determination theory also recognizes the individual's need for feeling competent and for acceptance into a community as important influences on motivation.

Goal-Orientation Theories

Various goal-based theories of motivation have identified two distinct orientations toward goal achievement: one related to learning/mastering a task and the other focused upon gaining approval for demonstrating competency. Goals focused upon acquiring skills and knowledge are referred to as task-involved goals, mastery goals, or learning goals, depending on the theory being referenced. Goals focused on being seen as competent are sometimes referred to as ego-involved goals, but more often referred to as performance goals (Elliot and Dweck 2005). Subsequent versions of the theory have refined these two main orientations, but are beyond the scope of this entry.

These goal orientations have a profound effect upon motivation, on both what individuals choose to pursue and the persistence with which they pursue it. For those who adopt learning goals, the choice is more likely to include a task that is new and challenging, which will provide the greatest opportunity for growth. If such a task presents a problem, the individual is likely to persist in order to further develop his skills and learn through the process. Performance goals, however, are often associated with familiar or easy tasks, those in which the individual can confidently demonstrate ability. Within such a goal orientation, encountering a problem indicates a lack of ability; therefore, when unforeseen difficulty occurs, the individual is likely to retreat from the task in an attempt to avoid demonstrating any incompetency.

In general, a teacher would want to maximize the level of mastery goal orientation in a class by making the classroom a safe place to take risks and to view errors as learning opportunities rather than indications of incompetence.

Important Scientific Research and Open Questions

Like other psychological constructs that are not directly observable, motivation constructs have been difficult to concretize, resulting in many different theories attempting to explain the same phenomena. Even the nature of motivation (is it a process, a characteristic, a state) is not universally agreed upon. With this lack of clarity comes a lack of reliability of measurement, which can pose difficulties for studying a phenomenon scientifically. Although everyone phenomenologically recognizes motivation as an important variable in learning, measures of it rely on self-report (which is unreliable) or behavior change (which involves circular reasoning). Several open questions arise from this dilemma. The first is the juxtaposition of the concepts of situated motivation versus self-regulation of motivation. In the former case, motivation is thought to be determined by environmental conditions, a stance consistent with behavioral psychology, but discussed more recently in the study of classroom goal structures and their impact on student motivation (Meece et al. 2006). In the case of self-regulation of motivation, it is the learner that controls his or her own motivation through active regulation strategies (Pintrich and Schunk 2002). These two frameworks offer differing recommendations for the study and enhancement of motivation. Modern theories, such as social cognitive theory, generally assert that the level of motivation is a result of the interaction between the individual and environment, with neither being clearly the dominant force.

A related source of interesting open questions is the relationship between intrinsic and extrinsic sources of motivation. To what extent and in what way does an extrinsic source of motivation dampen the impact of motivation that arises from the individual or the intrinsic value of the activity? The answers to these questions are particularly important to educators who wish to promote self-regulated, lifelong learning, but have difficulty getting students interested in the standard curriculum and often resort to grades as the source of motivation.

One step beyond is the impact of emotion on motivation, an area of research that is gaining in importance as more is learned about the brain in relation to behavior. The ability to monitor the brain's response to changes in the environment at many levels may actually provide a solution to the initial dilemma of this section: the need for a more reliable measure of motivation, which might lie in advances in monitoring neurological responding.

Cross-References

- ▶ Achievement Motivation and Learning
- ▶ Emotion(s) and Learning
- ▶ Learned Helplessness
- ▶ Motivation Enhancement
- ▶ Motivation, Volition, and Performance
- ▶ Motivational Variables in Learning
- ▶ Self-determination of Learning
- ▶ Self-efficacy of Learning
- ▶ Self-regulation and Motivation Strategies
- ▶ Volition for Learning

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Motivation Enhancement

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Synonyms

Achievement motivation enhancement; Achievement motivation intervention; Engagement enhancement; Engagement intervention; Motivation intervention

Definition

Academic motivation has been described as students' energy and drive to engage, learn, work effectively, and achieve to potential (Martin 2007). Motivation enhancement refers to intervention (e.g., counseling, pedagogy, parenting, coaching) aimed at facilitating and improving motivation (Martin 2008). Motivation plays a large part in students' interest in and enjoyment of learning. Motivation also underpins achievement (Pintrich 2003). Research has shown that a variety of factors impact students' motivation, including the nature of pedagogy they receive, relationships they have with their teachers, parents' attitudes toward and expectations for their children, peers, class climate, school culture and structure, sociodemographic status, gender, and age (see Martin 2007 for a review). Many of these have been the target of motivation enhancement efforts.

In critical reviews of motivation research, it has been suggested that research oftentimes yields limited practical implications and applications and that there is a need to devise research that advances scientific understanding and which has applied utility. Hence, there have been calls to give greater attention to use-inspired basic research in education and psychology contexts (Pintrich 2003). Critical reviews of motivation research also point to the fact that such research is diverse and fragmented. As a result, there have also been calls for more integrative approaches to its research and theorizing (Pintrich 2003). It is in this context that the Motivation and Engagement Wheel (Martin 2007) was developed (with an accompanying measurement tool, the Motivation and Engagement Scale, (Martin 2009)). The Wheel comprises 4 higher order and 11 first-order factors, as follows: adaptive cognition (self-efficacy, valuing, mastery orientation), adaptive behavior (planning, task management, persistence), impeding/maladaptive cognition (anxiety, failure avoidance, uncertain control), and maladaptive behavior (self-handicapping, disengagement). Martin's multidimensional motivation framework has been effective in driving multidimensional measurement and intervention (motivation enhancement) work (e.g., Martin 2007, 2008).

Theoretical Background

Research has sought to examine the effect of intervention programs on students' academic motivation. Many of these interventions have been successful in enhancing students' self-concept, attributional patterns, goal orientations, and sense of control, as well as reducing students' anxiety (see Martin 2008 for a summary). However, the bulk of intervention studies focus on relatively few dimensions of students' motivation. In response to calls for more integrative approaches to the study of motivation enhancement (see Pintrich 2003), more recent work has sought to develop approaches underpinned by multidimensional frameworks. Martin (2008), for example, applied a "Prepare-Generate-Reflect-Close" procedure that was aimed at: (a) providing an advance organizer for the target motivation factor and key activities aimed at enhancing it, (b) enabling the student to generate and construct key learnings relevant to their motivation, (c) providing an opportunity for the student to reflect on key messages developed through these learnings, and (d) then attaining closure on the target motivation factor through having mentors sign off the activities for that week. Using a pre- or post-treatment/control group design, it was found that the motivation intervention brought about significant gains in motivation. These findings attested to the potential for multidimensional educational interventions for enhancing students' motivation.

This recent work has provided guidance on the overall structure of motivation enhancement intervention (i.e., "Prepare-Generate-Reflect-Close"). Importantly, many researchers have provided substantive guidance on strategies targeting specific facets of motivation. As described in Martin (2007), the Motivation and Engagement Wheel (and its 11 first-order motivation factors: self-efficacy, valuing, mastery orientation, planning, task management, persistence, anxiety, failure avoidance, uncertain control, self-handicapping, disengagement) can be a basis for intervention to enhance key dimensions of student motivation. The following is advice from Martin (2007, 2009) targeting these 11 dimensions (see also Covington 1992; McInerney 2000).

The development of *self-efficacy* can involve restructuring learning so as to maximize opportunities for success – for example, through individualizing tasks, addressing and enhancing students' (negative) beliefs about themselves, and developing skills in effective goal-setting that are likely to lead to success and which provide a basis for enhancement of one's self-efficacy. Central to students' *valuing* (of school) is their view that school is relevant and important. Students' perceptions of significant others' valuing impact on the value they attach to school. This underscores the importance of educators being positive role models for valuing what they teach and parents being positive role models for valuing (school) and subjects within it (Covington 1992; Martin 2007, 2009; McInerney 2000).

Goal theory provides direction for enhancing students' *mastery orientation*, *planning*, *task management*, and *persistence*. Mastery orientation centers on students' ability to focus on mastery and the task at hand; thus, encouraging students to focus less on comparisons with others or evaluative concerns and more on the task at hand and the effort needed to master the task is one means of developing a greater mastery focus. It is also suggested that a focus on developing students' self-regulatory skills is an important means of enhancing their capacity to plan, manage their study, and persist in the face of challenge. This can encompass using time more effectively, prioritizing, and developing strategies for doing and checking schoolwork as it is being completed (Covington 1992; Martin 2007, 2009; McInerney 2000).

There are numerous ways to address *uncertain control*. First, when students see the connection between their effort (a controllable element of their schoolwork) and academic outcomes, they are likely to gain a greater sense of control over their ability to attain or repeat success or avoid failure. Control is also developed by providing feedback in effective and consistent ways. For example, it is important for educators to provide feedback on students' work that makes it clear how they can improve. Further, control is enhanced when educators administer consequences that are directly contingent on what students do – often inconsistent response contingencies create uncertainty in students' minds as to what they did to receive that consequence. It is suggested that control is particularly pivotal for addressing students' *disengagement*. Through chronic levels of low control, disengaged students have given up to the point of not even trying to avoid failure. These students believe there is little or nothing they do to affect academic outcomes in their life and are generally disengaged from tasks and display a helpless pattern of motivation. A key factor underpinning *failure avoidance*, *anxiety*, and *self-handicapping* is a fear of failure. Research suggests that ways to reduce students' fear of failure include promoting the belief that mistakes provide diagnostic information about how to improve, can be important ingredients for future success, and do not imply that the student is lacking in worth. When fear of failure is addressed, there are fewer bases for anxiety, avoidance, and self-handicapping (Covington 1992; Martin 2007, 2009; McInerney 2000).

Important Scientific Research and Open Questions

An important test of the effectiveness of motivation enhancement is to assess the link between improved motivation and subsequent learning. It has been contended that changes in motivation are likely to lead to changes in learning (Martin 2007). However, this needs to be tested in the context of an intervention that investigates changes in motivation and the subsequent impact this has on academic outcomes.

It is possible that some motivation factors are more desirable as intervention targets than others. For example, some motivation factors may be more closely associated with learning, achievement, and attainment and thus might receive greater prominence in enhancement efforts. Or, some motivation factors might be relatively easy or rapid to enhance and thus more deserving of priority in pedagogy and counseling. Research is needed to guide practitioners in decisions on matters such as these.

There may be occasions when motivation should not be the focus of intervention and assistance. If, for example, motivation is a target to assist learning in mathematics, perhaps it is more advisable to provide additional mathematics instruction (e.g., tutoring). Or, if motivation is the target of intervention to improve homework compliance, perhaps a home-/parent-focused intervention would be more effective. There is only limited time to allocate to educational enhancement efforts and this may mean motivation is not the focus on some occasions. On other occasions there may be a need for joint/integrated motivation and "other" intervention such that, for example, motivation intervention *and* mathematics tutoring are provided. Research is needed to provide further information as to when motivation should be a target for educational enhancement efforts, when other factors (e.g., tutoring, home-school links) should be the target, and when both should be the target.

It is also the case that motivation enhancement research tends to be short term. We do not know a great deal about the effects of motivation enhancement efforts over the medium to longer term. Are enhancement effects maintained 6 or 12 months later? If not, what motivation factors are most susceptible to dilution over time and what intervention is needed to maintain them? It might be the case that enhancement efforts are more effective for some students than others (i.e., a moderation effect), in which case it is important to know who is best assisted (and why) and who is not assisted (and why not).

Finally, much of this discussion has implied that motivation is state-like. It is probable, however, that there are also trait dimensions to motivation. For example, motivation is also likely to be a function of one's personality (e.g., conscientiousness), with some students perhaps more likely to be energized and engaged and others anxious and avoidant. The relative salience of state and trait dimensions of motivation is an important direction for research. There might also be yields in exploring the neurological and genetic bases of motivation. Advances in brain-based research and sophisticated genetic methodologies open up new opportunities for understanding motivation. The task then is to apply these findings to better develop and target motivation enhancement efforts.

Cross-References

► Academic Motivation
► Achievement Motivation and Learning
► Engagement in Learning
► Incentives and Student Learning
► Motivation, Volition, and Performance

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Motivation Intervention

► Motivation Enhancement

Motivation to Learn

► ARCS Model of Motivation
► Self-Efficacy for Self-Regulated Learning

Motivation, Learning, and Performance

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Synonyms

Integrative theory; Motivation; Motivational design; Volition

Definition

The motivation, volition, and performance (MVP) model refers to a theory that integrates numerous theories, concepts, and design processes related learner motivation, self-regulatory behaviors, and learning as reflected in performance. This MVP theory portrays the various integrated theories and concepts that are represented in a systems diagram (MVP model) that illustrates how they are connected with regard to inputs, processes, and outputs and also preserves the theoretical integrity of each component. This type of theory can be characterized as a concatenated theory (Keller 1983) or a constructive theory as Einstein called it (Keller 1983) in contrast to a hierarchical theory. A concatenated theory consists of an assembly of explanatory components pertaining to a central phenomenon, in the present case learner motivation and performance. This is in contrast to a hierarchical theory in which the component laws and principles are derived from a set of basic principles, as in a hypothetico-deductive theory.

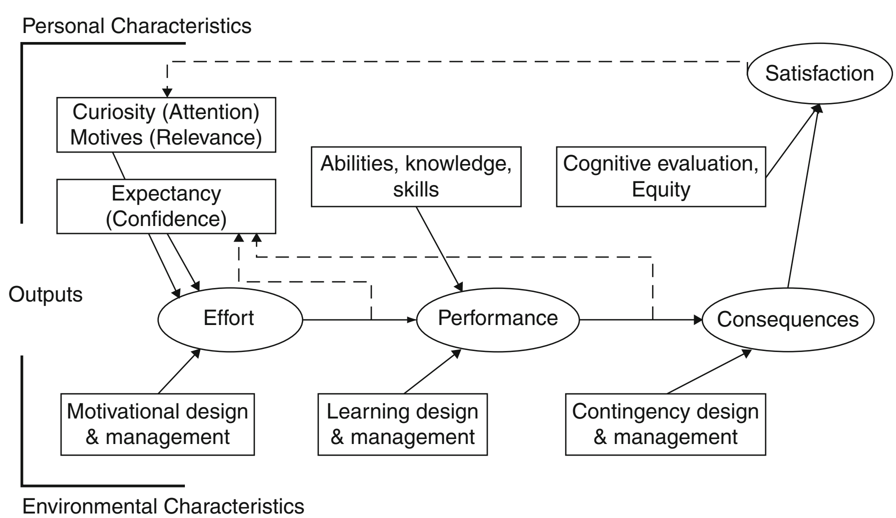
Theoretical Background

The MVP theory grew out of an earlier theory called the "macro model of motivation and learning" (Keller 1983) which postulated that the primary influences on learners' efforts to succeed are internal, or personal, motivational characteristics combined with environmental characteristics (Fig. 1). *Effort*, the first outcome variable, has a direct influence on *performance* as do the learner's background knowledge, abilities, and skills combined with environmental influences related to instructional design and resources. The *consequences* of a student's performance, such as grades or praise, result from the way in which reinforcement contingencies are managed. And, finally, *satisfaction* with the learning experience results from the combination of the actual consequences and the learner's cognitive evaluation of them. High satisfaction leads toward continuing motivation as related to having a positive value for the given goal activity.

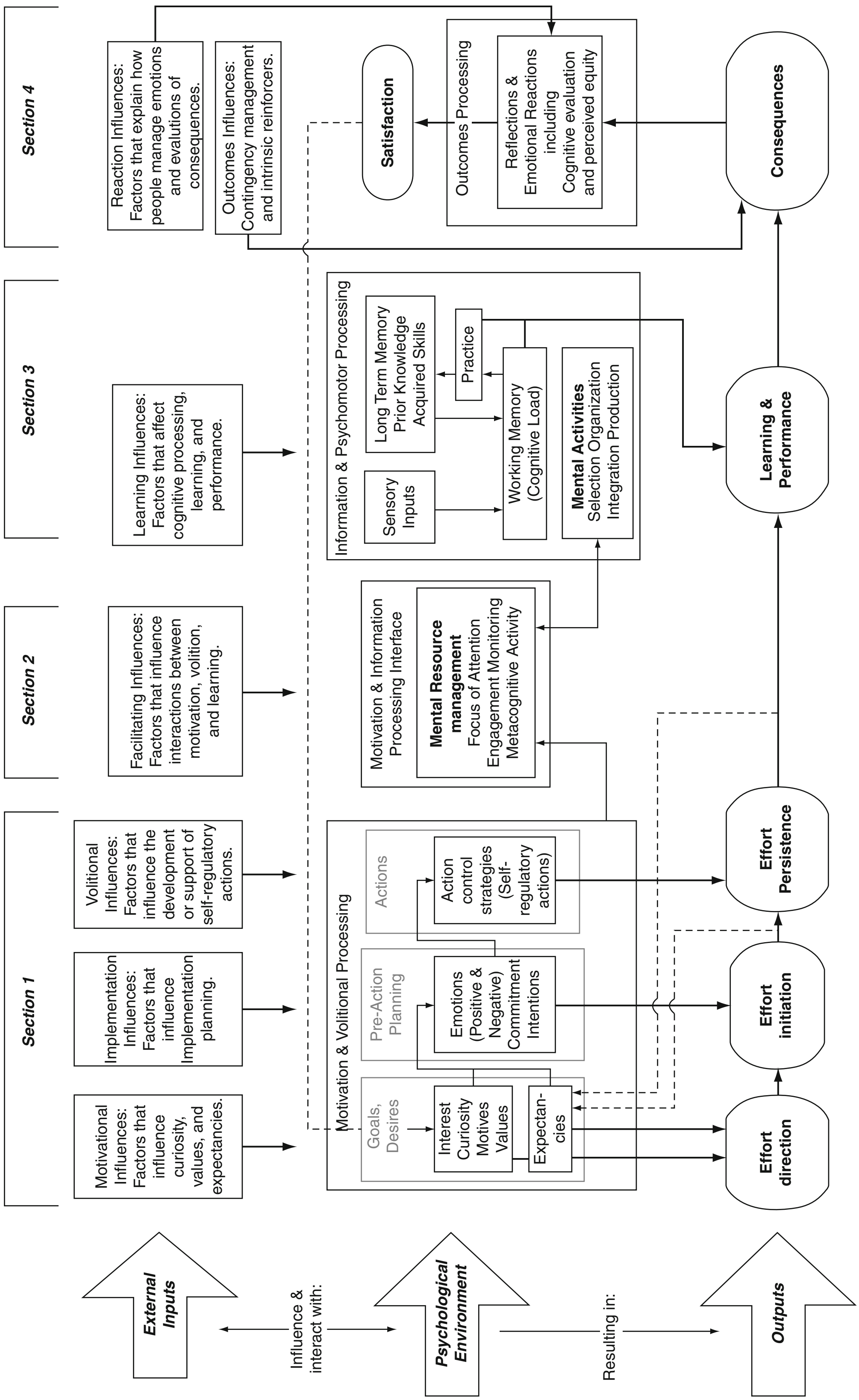
This macro model was useful in guiding inquiry on motivation and learning and providing a basis for identifying design issues. For example, audience analysis can be used to identify sources of motivation and learning problems and to then design solutions that incorporate the appropriate strategies (environmental stimuli) with regard to motivation, instructional design, and contingency management. As a process model, this macro model illustrates the relationships among various structures but does not provide detailed illustrations of the activities that occur within the major components. For that, one would have to look into the theories and procedures within the given component. For example, with regard to the expectancy-value part of the model, it is assumed that the goals with the highest valence will automatically result in action in the form of effort to accomplish the desired goals. Although this is true, this example also illustrates one of the shortcomings of the model that led to its expansion. Descriptions of the macro model and the associated ARCS model explain the challenges of sustaining learners' efforts to accomplish a given goal despite distractions and competing goals, but the model does not include specific concepts or procedures pertaining to this problem. Therefore, the theory and its associated model were expanded to explain the internal volitional, or self-regulatory, processes together with external supports that can assist learners in moving from goal selection to goal-directed actions and persistence. The revised model includes volition as a distinct component and also expands other areas to include such things as intentions and information processing theory.

The motivational section of the MVP model that pertains to goal setting and persistence (Fig. 2, Section 1) has been expanded to include three stages of effort. The first is *effort direction* which refers to goal choice and which is explained primarily by expectancy-value theory as in the earlier model. After selecting a goal, the next step is to act on it and this is facilitated by having strong commitment, or intentions, to achieve the goal which leads to the outcome labeled *effort initiation*. The third phase is to sustain one's efforts to achieve a goal. This is facilitated by actions that protect one's goal intentions from distractions and other obstacles. If a person's motivation to achieve a goal is high enough, the person is not likely to be deflected from efforts to achieve it. But in many instances, especially when one's motivation is primarily extrinsic and the strength of a given goal is low, it might be beneficial to employ self-regulatory strategies, or action control strategies (Kuhl 1987) that assist with maintaining one's *effort persistence*. All of these effort outcomes are also influenced by motivational strategies that are implemented in the learning environment (Fig. 2, Section 1) and other *external input* aspects of the environment such as social support, competing values, and so forth.

The remaining motivational components in the MVP model are related to *satisfaction* (Fig. 2, Section 4) and are essentially the same as in the original model (Fig. 1). However, this section is now called *outcomes processing* and it includes both cognitive reflection and emotional processing. Also, note that the influence of behavior management by means of reinforcement contingencies has been retained from Keller's original model, but there is a new block (Fig. 2, Section 4) in the external inputs section.



Motivation, Learning, and Performance. Fig. 1 A macro model of motivation, learning, and performance (Based on Keller 1983)



Motivation, Learning, and Performance. Fig. 2 The integrative model of motivation, volition, and performance (MVP) (Based on Keller 2008)

It incorporates strategies that can be implemented to influence how people manage their emotional and evaluative reactions to events. For example, providing guidance on personal management strategies such as mindfulness and support groups have been shown to help people manage their emotional and cognitive reactions to events as well as to help them move forward in a more productive state of mind.

Another important characteristic of the MVP model is its incorporation of information processing theory. However, a limitation of information processing theory in general is that it does not include motivational or volitional considerations. Astleitner and Wiesner (2004) proposed an integrated theory of information processing and motivation that includes motivational processing as well as elements of mental resource management (Fig. 2, Section 3). They draw primarily on Kuhl (1987) who postulated that such things as wishes, intentions, values, and emotions are also part of working memory in addition to the traditionally recognized perceptual and cognitive processing components. Motivational components such as goal setting and action control are connected to the information processing model by means of mental resource management activities such as attention, engagement, and monitoring which have been placed in a special section of the MVP model (Fig. 2, Section 3) in order to illustrate how they interface between motivation and information processing. It should be noted that Astleitner and Wiesner's (2004) use of the term "attention" refers to actions that facilitate learning, such as providing cues to focus attention to salient parts of the mental tasks at hand. This is different from using "attention" in the motivational sense (Keller 2008) which refers to stimulating and sustaining arousal and curiosity. Astleitner and Wiesner's model also lists several mental management activities that are related to the filtering of input information and the control processes in working memory (Fig. 2, Section 4). These processes are helpful in identifying motivational challenges to learning. For example, failure to exercise effective control over relevant input information can lead to excessive cognitive load and demotivation.

Two other distinctive characteristics of the information and psychomotor processing component of the MVP model are the explicit references to *cognitive load* and *practice*. It does not delineate the elements of dual processing theory due to the already complex structure of the model, but they are presumed to be within the sensory inputs and working memory components. Although there are numerous control processes within working memory, attention is called to the concept of cognitive load (Sweller 1994) in the present model. This variable is presumed by many to be a key factor in designing instruction, especially in regard to designing instruction for the teaching of complex cognitive skills where the stimulus arrays can be complex and distracting and have a direct influence on motivation. Also, the concept of practice is included because, as shown by Ericsson (2006), the type of practice that distinguishes superior performers, called *deliberate practice*, is a behavior that combines psychomotor, cognitive, and motivational elements in the development and maintenance of expert performance.

Important Scientific Research and Open Questions

Traditional design and research approaches typically do not allow for the consideration of multiple, interacting influences on motivation or offer adequate guidance for distinguishing among the many symptoms versus causes of motivational difficulties among learners. There are many theories and models that explain aspects of motivation, volition, and learning but most of them tend to stand alone as relatively independent areas of inquiry. For example, research on motivational variables such as need for achievement curiosity, or attributions usually include learning as a dependent variable, but they do not integrate multiple aspects of motivation, environmental design, and learning theory.

In contrast to this situation, a cardinal premise underlying the MVP theory is that it is beneficial if not actually necessary to integrate the primary theories and concepts related to motivation and learning in order to provide an adequate basis for learning environment design and inquiry. Even though the primary focus of this entry is on learner motivation, including the initial motivation of learners and their continued motivation (volition), other components of the overall learning environment must also be taken into consideration in designing research and practices that are ecologically valid; that is, studies that can be implemented in an action environment and can account for a variety of influences on motivation and learning.

For example, studies of the concept of computer rage began as an investigation of a particular phenomenon and the causes, based on self-report and observational measures, were presumed to be errors, time delays, and emotional reactions. The most commonly used theoretical explanations were based on the traditional frustration-aggression hypothesis. However, this provides only a partial explanation because even though it has been confirmed consistently in many studies that aggression is caused by frustration, the converse is not true; that is, frustration does not always lead to aggression. This has led to research on ways of alleviating frustration in ways that avoid aggression. The primary methods include removal of the causes of frustration by improving the quality and reliability of computer interfaces and by providing frustration alleviating feedback in the form of apologies and other kinds of messages (Klein et al. 2002). To provide theoretical support for this approach, researchers are investigating theories of human emotion and emotional management as a basis for designing computer interfaces that are sensitive to emotional changes in the user and then providing an appropriate response.

Even though this area of inquiry is broadening, it could perhaps expand even more quickly into relevant and potentially useful areas by examining an integrative theory such as that represented in the MVP model. For example, if we try to give an overall characterization of this research with reference to the MVP model, we can see that user efforts to perform well (refer to the *outputs* row, Fig. 2) are frustrated by the environmental conditions (*external inputs*) that either facilitate or restrict performance due to poor man–machine interfaces. These deficiencies result in emotional frustration (*outcomes processing*) and a frequent tendency to behave aggressively toward the equipment. The concept of frustration-aggression also falls under outcomes processing as an emotional reaction. However, not everyone responds in the same way to frustration or to interventions such as apologies from the computer, which some people regard as inappropriate "anthropomorphizing" of the machine. It might be fruitful to incorporate investigations into goal setting (the stronger one's goal motivation, presumably the greater one's frustration in being thwarted from achieving the goal), volition to better understand how to immunize users against these inevitable frustrating obstacles in computer environments, and the influence of interface design on ease of information processing and cognitive load in order to preserve as much working memory as possible for the task at hand. It is, of course, possible and even perhaps likely that researchers would eventually identify some of these avenues of inquiry, but the contention of this entry is that an integrative model can facilitate and speed up the process, and even perhaps stimulate ideas that would not have otherwise occurred to people.

There are other examples of integrative research (Keller 2008) that range from controlled variable studies as in the preceding example to applied studies that are more in the nature of action research, or design-based research. However, this is a recently formulated theory and it can benefit from a variety of studies that illustrate and validate the overall model.

Cross-References

- ▶ ARCS Model of Motivation
- ▶ Motivation and Learning: Modern Theories
- ▶ Motivation Enhancement
- ▶ Motivation to Learn
- ▶ Motivational Variables in Learning
- ▶ Self-regulation and Motivation Strategies

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Motivational Design

► ARCS Model of Motivation
► Motivation, Learning, and Performance

Motivational Variables in Learning

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Synonyms

Commitment; Desire; Willingness

Definition

In order to define the phrase "motivational variables in learning," learning should be defined first. Learning refers to "change in abilities, attitudes, beliefs, capabilities, knowledge, mental models, patterns of interaction or skills" (Spector 2001, p. 313). Motivational variables in learning can be defined as the attributes that make a learner desire to pursue such changes. Not only the initiation of a desire, but also its continuation is necessary for the desire to result in change; that is, to be considered a motivational learning variable, a learner's desire ought to be sustained until there is a change in the learner indicating that learning has occurred. There are numerous variables that might be associated with the initiation and continuation of a learner's willingness to learn, including interest, perceived relevance, activation of prior knowledge, goal orientations, self-efficacy, epistemological beliefs, emotions, autonomy, satisfaction, and more. However, the discussion of these variables is not the focus of this entry; instead, motivational variables are discussed in terms of volition which is a characteristic of the learner associated with the continuation of a desire and its transformation into sustained action (e.g., in the form of sustained commitment to a program of study). Volition is clearly associated with a learner's willingness to continue to learn, but it is also associated with a learner's ability to control negative emotions and other things that might impede learning. The construct of volition is perhaps a better way to treat the many individual motivational variables that have been investigated and discussed in the research literature.

Theoretical Background

Although motivation is not the same as volition (Corno 2004), the two constructs are not mutually exclusive; rather, motivation, defined as "the process whereby goal-directed activity is instigated and sustained," originally encompassed volition (Pintrich and Schunk 2002, p. 5). The early work of James (1890) distinguished between two components of motivation – will and volition – but that distinction was not maintained in the research literature on motivation. Keller (2008), in his review of the literature on motivation, reintroduces this distinction; "will" refers to a person's intention to pursue a goal and "volition" refers to actions taken to fulfill that intention. In this vein, Pintrich and Schunk's (2002) definition of motivation appears to indicate both parts, that is, the process of a goal-directed activity being instigated seems to refer to will and the process of a goal-directed activity being sustained seems to refer to volition. A reciprocal relation is found between motivation and volition, meaning that a person's will, desire, and intention to pursue a goal influence the person's actions to achieve the goal, and vice versa. Pintrich and Schunk's (2002) notion of motivation indexes corresponds to the reciprocal relation between motivation and volition, although they do not use the term of volition. That is, the indexes contain "choice of tasks, effort, and persistence" (Pintrich and Schunk 2002, p.13), which represent the critical components of volition mainly discussed in volition research (e.g., Corno 2004).

Just as the motivation literature refers to the concept of volition, the volition literature includes the concept of motivation. For example, Gollwitzer and Brandstätter (1997) propose a model illustrating how to transform desires to actions, called the Rubicon model of implementation intention(Gollwitzer and Brandstätter 1997). The model consists of four phases, which are pre-decisional, pre-actional, actional, and post-actional phases, with the first phase indicating motivation with the steps of wishing, deliberating, and choosing. Kuhl's (1987) action control theory also includes motivation. The theory specifies a set of control strategies that can help a person overcome distractions interfering with the person's intentions and actions, and motivation control is one of the strategies.

Important Scientific Research and Open Questions

Volition as a critical motivational variable works for willingness and ability to remain focused and on task until learning occurs. However, most empirical studies have separated the construct of volition from the construct of motivation and vice versa. Although understanding motivation and volition together is beneficial for the design and development of effective learning and teaching environments, most empirical studies have separated the two. There are only a few studies with an integrative perspective of motivation and volition (e.g., Kim and Keller 2008). In other words, there is a tendency to study on (a) how people form their will, desire, and intention to pursue their goals without further inquiries regarding their persistent actions in pursuit of the goals (i.e., research on motivation excluding volition), and (b) how people take actions on their goals without attempts to understand the underlying reasons for the formation of their goals (i.e., research on volition excluding motivation). In addition to the need for an integrative approach, the need for timely measurement of volition as a motivational variable is necessary for detection and feedback that optimize motivational variables to learn in actual learning situations.

Cross-References

► Achievement Motivation
► Affective and Emotional Dispositions of/for Learning
► Affective Dimensions of Learning
► ARCS-Model of Motivation
► Attribution Theory of Motivation
► Emotion Regulation
► Expectation and Attention in Learning
► Mood and Learning
► Motivation
► Motivation and Learning: Modern Theories
► Motivation Enhancement
► Self-efficacy for Self-regulated Learning
► Self-regulated Learning
► Self-regulation and Motivation Strategies
► Understanding Intrinsic and Extrinsic Motivation

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Motor Learning

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Synonyms

Motor skill learning; Motor skill acquisition

Definition

Motor learning reflects a relatively permanent change in a person's capability to perform a motor skill (Schmidt and Lee 2005). Learning occurs as a function of practice, and individuals typically go through various stages of learning. Fitts and Posner (1967) proposed three learning phases: the cognitive, associative, and autonomous phase. The cognitive phase is characterized by the learner trying to figure out what exactly needs to be done. Considerable cognitive activity is typically required in this stage, in which movements are controlled in a relatively conscious manner. During this phase, learners often experiment with different strategies to find out which ones work or do not work in bringing them closer to the movement goal. Also, learners tend to pay attention to the step-by-step execution of the skill, which requires considerable attentional capacity. The result of using conscious control strategies is that the movement is relatively slow, abrupt, inefficient, and performance is rather inconsistent.

Once a learner has acquired the basic movement pattern, the associative phase of learning begins. It is characterized by more subtle movement adjustments. The movement outcome is more reliable, and the movements are more consistent from trial to trial. Inefficient co-contractions are gradually reduced, and the movement becomes more economical. In addition, at least parts of the movement are controlled more automatically, and more attention can be directed to other aspects of performance.

After extensive practice, a performer will usually reach the autonomous phase, which is characterized by fluent and seemingly effortless motions. Movements are not only accurate, with few or no errors, but also very consistent. In addition, movement production is very efficient and requires relatively little muscular energy. The skill is performed largely automatically at this stage, and movement execution requires little or no attention.

Theoretical Background

Motor learning research is generally concerned with identifying variables that affect the learning of motor skills. Typical experiments involve two or more groups of participants practicing a motor task under different conditions (e.g., feedback frequencies, movement demonstrations, attentional focus instructions) during a practice phase. Yet, because learning reflects a relatively permanent change in a person's capability (Schmidt and Lee 2005), researchers use ► retention tests (or ► transfer tests) that are performed after an interval of at least one day, but sometimes several days or even weeks, to assess what was actually learned under different practice conditions. The purpose of the retention interval (i.e., interval between the practice phase and retention/transfer test) is to give any temporary effects of different practice conditions (e.g., caused by different degrees of fatigue or motivation) a chance to dissipate – leaving only the relatively permanent, or learning, effects. Thus, retention or transfer tests are used to determine which practice condition was most conducive to learning. Aside from the temporal delay relative to the practice phase, an important aspect of these tests is that all groups perform under the same conditions. Only then can the performance of different groups be compared directly, and researchers can draw conclusions about the effectiveness of different practice conditions for motor learning.

Important Scientific Research and Open Questions

In the past few decades, research in motor learning has come a long way in describing and explaining how performance and learning of motor skills is affected by different factors. These include, for example, the distribution of practice (massed vs distributed), types of practice (e.g., physical, observational, mental), guidance (e.g., verbal, physical guidance) versus discovery learning procedures, implicit learning, the feedback provided to the learner (e.g., timing, type, frequency), the organization of practice (e.g., practice variability, contextual interference), self-controlled practice (self-/learner-controlled vs yoked), and attentional focus instructions (internal vs external focus) (see Schmidt and Lee 2005).

For example, observational practice has been demonstrated to be an effective method in the learning of motor skills. It can make unique and important contributions to learning especially when observation is combined with physical practice. Neuroimaging experiments have shown that a set of common neural structures are activated during both action production and action observation. Specifically, mirror neurons in the premotor and posterior parietal cortex have been shown to be activated not only during the execution of actions but also when observing somebody performing those actions. These seem to be the basis for the effectiveness of observational practice.

Another important variable in the learning process is feedback. Feedback examined in the context of motor learning research usually involves information about the outcome (knowledge of results) or the quality of the movement (knowledge of performance). Much research in the motor learning domain has been concerned with the informational function of feedback, that is, its role of providing *information* about an individual's performance in relation to the task goal. In this context, studies have addressed issues such as the effect of feedback frequency, timing, accuracy, or error estimation. This research has provided important insights into the role of augmented feedback for learning. Recent findings indicate that the *motivational* properties of feedback can have an important influence on learning as well. For example, studies have shown that providing learners with feedback after successful performance, rather than less successful attempts, results in more effective learning, presumably because of its positive motivational effects.

Another important line of research is related to self-controlled learning. There is converging evidence that the effectiveness of skill learning can be enhanced if learners are given some control over the practice conditions. For instance, having learners decide after which trial they want, or do not want, to receive feedback has been demonstrated to lead to more effective learning than predetermined feedback schedules. Other studies have found advantages of self-control over the use of physical assistive devices (for the learning of balance tasks) or video demonstrations of a skilled performer, compared to yoked control conditions. Self-controlled practice might be more in line with the learner's specific needs and desires. In addition, it presumably satisfies learners' fundamental psychological need for autonomy.

Finally, ample experimental evidence has demonstrated that directing a learner's attention, through instructions or feedback, to his or her *movements* (i.e., inducing an internal focus) is relatively ineffective. In contrast, directing attention to the intended *movement effect* on the environment, such as the movement of an implement, object, or support surface (i.e., inducing an external focus), results in more effective performance and learning. An external focus is associated with greater movement ease, automaticity, or fluidity. Conversely, focusing on personal movements results in a more cognitively conscious type of control, thereby constraining the motor system and disrupting automatic control processes. A focus on the intended movement effect facilitates the utilization of unconscious or automatic processes. Thus, an external focus speeds the learning process so that a higher skill level is achieved sooner.

Cross-References

► Automatic Information Processing
► Learning-Related Changes of β-Activity in Motor Areas
► Motor Schema(s)
► Retention and Transfer
► Self-Regulated Learning
► Sensorimotor Adaptation

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Motor Schema

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Synonyms

Recall schema; Recognition schema

Definition

Motor schemas (schemata) are memory representations of movement parameters (recall schema) or the sensory consequences of movements (recognition schema). According to schema theory (Schmidt 1975), the production of a movement pattern involves a ► generalized motor program, or GMP (i.e., a set of motor commands that is specified before movement initiation), that is retrieved from memory and then adapted to a particular situation. In order to be flexible, the motor system must learn the relations between the initial conditions (e.g., distance between the football in one's hands and the receiver), the generated motor commands (e.g., timing and forces to be generated during the throw), the sensory consequences of these motor commands (e.g., proprioception of arm movement), and the outcome of the movement (e.g., actual distance of the throw). In schema theory, these relationships are represented in motor schemas. The recall schema represents the relationship among the initial conditions, movement parameters (e.g., absolute time, absolute force), and movement outcome. It is used for movement production, specifically, to compute and select the appropriate parameters necessary to achieve the movement goal. The recognition schema is the relationship among the initial conditions, sensory consequences, and movement outcome. It is used for movement evaluation, that is, it enables the performer to evaluate the outcome, even in the absence of exteroceptive feedback.

Theoretical Background

In 1975, Richard A. Schmidt published an influential motor learning theory in a paper, entitled "A schema theory of discrete motor skill learning." In contrast to Adams' (1971) closed-loop theory, it provided an explanation for the control and learning of both rapid and slow movements, and was a more parsimonious account of how the numerous movement variations that humans are capable of performing are produced and stored in memory. The memory representations underlying this capability are the generalized motor program (GMP) and motor schemas (i.e., recall and recognition schema). The GMP is an abstract movement representation that governs a class movement (e.g., one's signature, golf swing, overhand throw). Movement variations within a class share invariant features such as the sequencing of sub-movements, relative timing, and relative forces. These are inherent in the GMP. However, movements governed by a GMP can be "scaled" across various superficial dimensions by the assignment of movement parameters, such as absolute time, absolute force, and the specific muscles used, via the recall schema. Thus, when movements governed by a GMP are scaled in this way, the sequencing, relative timing, and relative force are assumed to remain essentially invariant, as if the movement could be systematically "compressed" or "expanded" in both amplitude and time. Importantly, the GMP and motor schemata were proposed as independent memory representations that could presumably be learned independently of each other. That is, while schema theory did not address how GMPs were learned – but rather presumes their existence – it made important predictions regarding the learning of motor schemata.

A fundamental prediction of schema theory is that variable practice within a class of movements (i.e., practice in parameter selection) enhances a learner's capability to assign parameters in future situations. That is, compared to constant practice experience, or limited variability in practice, variable practice facilitates the development of a schema rule. Thus, by enhancing the schema rule, variable practice should also facilitate the selection of novel parameters. Furthermore, if any of the four types of information is unavailable following a movement, no schema updating (learning) can occur. For example, if a learner does not know whether the produced action was correct (no information about the movement outcome), the schema cannot be updated. Finally, incorrect movements may also provide learning opportunities and allow for development of more precise error detection and correction mechanisms. An incorrect movement produces the same types of information as correct movements, and can thus be used to update the schema.

Important Scientific Research and Open Questions

Schema theory has played an important role in the field of motor behavior. It continues to play a historical role, although many researchers do not consider the theory a viable theoretical perspective anymore. One reason for this is that some of the assumptions of the theory have not been fully supported in subsequent research. Nevertheless, the original theory proposed a number of constructs that have received empirical validation (for reviews, see Schmidt 2003; Shea and Wulf 2005).

Numerous experiments have demonstrated the independence of the GMP and movement parameters. For example, certain practice conditions (e.g., feedback frequency, blocked versus random practice) have been shown to impact the relative (GMP) and absolute characteristics of the movement (parameters) differently – thus supporting the theoretical dissociation of GMP and parameterization processes.

Variable practice was thought to provide learners with a wider range of specified parameters and associated movement outcomes that were abstracted to form the rule for specifying future parameter requirements (i.e., recall schema). This notion led to the variability of practice hypothesis – the main prediction of schema theory, which resulted in a flurry of experiments testing this idea. Indeed, there is considerable evidence in support of the prediction that schema learning is enhanced by variable as opposed to constant practice.

However, it appears that the scheduling of parameter variability (random or blocked practice) also plays a role in schema learning, and not just the presence or absence of variability. This is not in line with a strict interpretation of schema theory, according to which these practice regimens should result in similar schema learning. Furthermore, recent evidence suggests that massive amounts of practice of a particular movement variation in a movement class (e.g., free-throws in basketball shooting) can lead to the development of an especial skill, that is, one that represents a highly specific variation within that class and is distinguished by superior performance relative to other variations within that class.

Overall, there has been fairly strong support for some of the basic assumptions and predictions of schema theory. However, some of the ideas proposed in schema theory need to be revised to accommodate more recent findings. As Schmidt (2003) put it, "...it is time the motor learning field developed a new theory for motor learning. If I were to do this, it would probably include many of the features of schema theory that have weathered the past 25 years. Also I would exclude or at least change many of the other features to include new data and thinking" (p. 373).

Cross-References

- ► Motor Learning
- ► Schema(s)
- ► Variability of Practice

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Motor Schemas in Robot Learning

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Synonyms

Basis behaviors for robot learning; Macro actions in robot learning; Movement primitives in robot learning

Definition

Motor schemas used for *robot learning* are sequences of action that accomplish a goal-directed behavior, or a task. Motor schemas in robot learning are also known as *movement primitives*, *basis behaviors*, *units of action*, and *macro actions*. Rather than representing the simplest elementary actions available to the robot, such as a simple command to a robot actuator, schemas and motion primitives represent a higher-level abstraction of robot actions, such as "avoid obstacles," "wander," "walk," "grasp a cup," and "move to goal." These schemas and motion primitives define control policies that are encoded with only a few parameters, and serve as the *basis set*, or *movement vocabulary*, of the robot. Such primitives are sufficient for generating the robot's entire repertoire of motions via the combination of schemas or primitives. The schema can serve as a basis for robot learning, since it provides an abstraction that can be represented with fewer parameters, thus reducing the complexity of robot learning. This reduction in learning complexity allows robot learning to scale to more complex robots or tasks, thus making practical applications tractable.

Theoretical Background

The use of motor schemas in robotics first became popular in the 1980s, especially with the work of Lyons and Arbib (1989), and of Arkin (1987). Their development of the motor schema concepts was inspired by similar concepts in psychology and the neurobiological sciences. These early researchers recognized that ideas for how motor behavior control is achieved in animals (e.g., frogs, as studied by Arbib) or in humans can provide a model for how similar behaviors can be created in robots. As defined in this early work, a robot schema consists of a list of input and output ports, a local variable list, and a behavior that defines how the input is processed to generate the output. Robot schemas can be of two broad types – *perceptual schemas* and *motor schemas*. Perceptual schemas, which can be embedded inside motor schemas, process input from environmental sensors on the robot to provide information to motor schemas. The motor schemas then generate output control vectors that represent the way the robot should move to achieve a goal, in response to the perceived stimuli. Schemas are independent, and can run concurrently with other schemas. A network of schemas can be built by manually connecting the outputs of one schema to the inputs of another. The output from multiple motor schemas can be combined using techniques from potential fields, such as vector addition. Motor schemas can be grouped to form more complex behaviors, which are sometimes called *behavior assemblages*. At the higher level, a nested network is established to represent collaboration among multiple robots.

In more recent years, roboticists have made less use of the *schema* terminology, preferring instead to describe robot design in terms of *movement primitives*, *basis behaviors*, *units of action*, or *macro actions*. These latter terms still capture many of the same ideas as the robot schema concept, although the implementation and realization of the movement primitives may be somewhat different from the original schema concept.

While human designers of robot systems can try to manually define the specific motor schemas and their interconnections that will be used in a robot system to solve a given task, this manual design process proves to be quite difficult for most practical applications. The difficulties arise in (1) the inability to anticipate the interactions of multiple schemas (or movement primitives), (2) the inability to discover the proper schema (primitive) combinations that achieve the required task, and (3) the unexpected interactions of the robot with the environment in which it operates. Because of these difficulties, learning approaches are preferred that enable the robot to learn and adapt its behavior from the fundamental behavior building blocks (i.e., schemas and/or movement primitives) provided by the human designer. Schemas and/or movement primitives are especially helpful in this context, as they provide the robot with fundamental building blocks that can be combined and parameterized as appropriate to achieve the task at hand. Learning techniques allow the robot to learn the appropriate sequences of schemas/behaviors that will accomplish the task, or the appropriate parameters with which to instantiate the schemas/behaviors, without requiring the designer to fully specify how the task should be accomplished. The overall rate of learning for a task has been shown to be increased by breaking down the task into subtasks, then learning at the subtask level, rather than monolithically at the higher-task level. Thus, the schema-based approach to robot learning provides a helpful abstraction for making the learning task achievable.

Important Scientific Research and Open Questions

A primary challenge in the use of motor schemas/primitives in robot learning is determining how to select, parameterize, sequence, or combine the predefined schemas or primitives to achieve a given task. One approach to this challenge is to have a human teacher or trainer to illustrate the desired task; the robot then seeks to emulate this demonstrated task. Much current research investigates this idea of robot learning via imitation of human actions, by building up from existing motion primitives (e.g., Breazeal and Scassellati 2002). In this approach, the robot must observe the human and determine which of the human's actions are relevant for the current task. This challenge includes the 3D perception problem of perceiving human movement through vision, as well as the attention problem, in which the robot selectively focuses on the aspects of the motion that are particularly relevant to the task to be learned. Once the action has been perceived, the robot must transform the perception into its own motor actions that achieve the same result.

However, it is not trivial for a robot to determine which motor schemas, or motion primitives, correspond to the demonstrated task. One approach (Schaal et al. 2003) is to execute each motor primitive, observe its outcome, and evaluate the result using a performance criterion that compares the similarity between the teacher's behavior and the robot's generated behavior. Another approach makes use of predictive forward models, in which each movement primitive tries to predict the next observed motion, based on the current state of the teacher. The motion primitive with the best prediction capabilities would be selected as the best match.

Another way of mapping the behavior of the trainer onto the robot's existing repertoire of basic/primitive capabilities has been proposed by Nicolescu et al. (2008). This work defines a behavior-based approach to learning from demonstration that uses behavior fusion to provide bottom-up generalization to new situations. This approach learns a coordination policy that linearly fuses the combined output of preexisting robot behaviors, which are expressed as schemas or potential fields, in a manner that matches the teacher's demonstration. The learning of this coordination is expressed as a fusion estimation problem, that is, state estimation in the space of linear combinations of primitive behaviors. For domains such as mobile robotics, fusion estimation is often subject to ambiguous changes in world state that are attributable to a large space of solutions. To account for this ambiguity and dynamic changes to the user's fusion policy, a particle filter is used to infer fusion estimates from robot sensory observations and motor commands. This learning technique allows for learning of superposition behavior fusion from existing innate robot primitives, and learning of sequential activities from multiple superposition fusion primitives.

Another approach for addressing this challenge is the work by Maja Mataric, which is based on the discovery of "mirror neurons" in monkeys, which fire when the monkey both observes a goal-oriented action, and when it performs the same action. The entire approach to robot imitation learning combines several cognitive approaches, including movement perception through a specialized selective attention system, direct sensory-motor mapping between the perceived and executable movement, movement generation through a system of composable motor primitives, and learning of new movements and skills by building on existing repertoire of motor primitives through classification and combination. In this work, three types of motor primitives are defined: discrete straight-line movements, oscillatory movements, and postural movements that define large subsets or whole-body arrangements of joints. Learning techniques such as reinforcement learning can be used to parameterize these primitives appropriately. In related work, certain types of motor primitives can also be learned by tracking the movements of humans, using Principal Components Analysis to extract the most relevant features from the motion data, and then using these features to reconstruct the original movement on the robot.

An alternative approach for robot learning of more complex tasks from primitive schemas is to enable the robot itself to explore its capabilities, rather than following the guidance of a human trainer. This type of approach is often called *constructivist* robot learning, which is a method for learning new knowledge and skills based upon past experience. This type of learning is recognized to be a common method used by humans from infancy to adulthood for lifelong learning. Because much of human learning seems to be based on schema building blocks, a similar approach is used in robotic applications. For example, Gary Drescher, as well as Harold Chaput, both developed schema-based constructivist learning models to computationally emulate an infant exploring the environment using very basic perceptual schemas and motor schemas. Their work concentrated on the biological verification of the constructivist point of view using very basic level schemas that reflect the inherent abilities of an infant.

A related approach to schema learning that does not involve a human teacher is the work of Tang and Parker (2008), who developed the SB-CoRLA (for Schema-Based, Constructivist Robot Learning Architecture) architecture, in which robots are able to build up combinations of schemas, called "chunks," which can then be used to improve the robot's efficiency in performing future tasks. The approach involves both an offline learning phase and an online learning phase. In the offline learning phase, which occurs when the robot is not busy performing tasks, the robot uses an evolutionary search technique to analyze its schema repository for highly fit partial solutions to tasks of interest to the robot. These solutions are then saved as chunks for future use in the online phase. In the online learning phase, the robot uses both the individual schemas and the schema chunks to quickly find good solutions for addressing the task at hand.

A unifying theme of all these approaches is the recognition that the use of fundamental building blocks, in the form of schemas, motion primitives, basis behaviors, etc., is a powerful way to make the robot learning problem tractable. By properly defining motor schemas for a given application, developed techniques can be used to select, parameterize, sequence, or combine the predefined schemas or primitives to enable the robot to achieve a given task. Many open issues remain, however. Certainly, more research is needed to deal with the perceptual understanding of the effects of motions, whether motions generated by human teachers or by the robot itself. Further, it is still currently difficult for robots to understand the high-level goals or objectives of demonstrated movement, and to determine how to best map these to the predefined repertoire of motion primitives. Additional open challenges include determining the appropriate set of schemas for a given application, and determining how to enable a robot to learn new schemas, in order to build up the available repertoire of motor schemas.

Cross-References

- ► Action Schemas
- ► Developmental Robotics
- ► Learning Action Affordances and Action Schemas
- ► Motor Schemas
- ► Robot Learning
- ► Schema-Based Architectures of Machine Learning
- ► Schema-Based Learning
- ► Schemas
- ► Sensori-Motor Schemas

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Motor Simulation

This theoretical term is widely used in the field of mental rotation and motor imagery. It refers to the ability of the observer to anticipate how he would act to manipulate a given object. The participant may simulate moving objects with his (her) hands to solve mental rotation problems.

Cross-References

- ► Mental Rotation and Functional Learning

Motor Skill Acquisition

► Motor Learning

Motor Skill Learning

► Motor Learning

Motor Skills

► Abilities and Learning: Physical Abilities

Movement Primitives in Robot Learning

► Motor Schemas in Robot Learning

Müller-Lyer Illusion

The label for the illusion in which two lines of equal length are seen to be unequal because of the arrows on either end: <—> versus >—<.

Multiagent Learning

► Multiagent Q-Learning Dynamics

Multiagent Learning System

► Learning Agent and Agent-Based Modeling

Multiagent Q-Learning Dynamics

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Synonyms

Chaotic dynamics; Hybrid dynamical systems; Multiagent learning

Definition

Multiagent Q-learning, a subfield of multiagent learning, is the study of the simple and effective Q-learning algorithm in strategic situations with more than one agent that may be learning. In environments with only one agent, Q-learning finds an accurate estimate of the action values using a straightforward computational rule. When there are two or more agents in a game, the interacting players behave according to some dynamical system that depends on the properties of the rule employed. Therefore, we must examine the system described by the learning players and the game payoffs as a whole.

Theoretical Background

Learning in an environment with multiple agents (a *game*) who might also be learning simultaneously is difficult because the effective reward for a given action may be constantly changing. This entry discusses the result of applying an update rule called ► ε-greedy Q-learning, a simple and yet powerful tool for finding optimal actions in unknown, static environments. Because this rule has such appeal from a design standpoint, it is interesting to ask what happens when several agents using it are put in a noncooperative situation. Its unique properties lead to previously unseen behaviors such as discovering cooperative outcomes even when there is an incentive not to cooperate and no way of remembering what the other player just did.

A central concept for understanding behavior game theoretically is the Nash equilibrium, defined as the combination of strategies where the payoff cannot be improved if any participant unilaterally deviates from its strategy. The simplest class of games has two players and two actions (2×2) and is played once. Each of these games has one of three possible types of equilibria. The first is where there exists a dominant action for one or both of the players, such that playing that action always results in a higher payoff than the other action in a single round. In this case, there is only one pure Nash equilibrium, like in the famous Prisoner's Dilemma game. The second type of equilibrium is where there are two pure Nash equilibria and one mixed Nash equilibrium. In coordination games like the Battle of the Sexes, there are two equilibria and one may happen to be more beneficial to one or both agents. Finally, some games have only one mixed Nash equilibrium in which the two players must choose actions stochastically to form an equilibrium. Zero-sum games like Matching Pennies fall into this category.

If a game is repeated, there are many possible equilibria and many strategies may exist. Most learning rules without a notion of state focus on guaranteeing a minimum security value, which is consistent with a Nash strategy. However, other rules can find substantially higher long-run rewards when played against like-minded players. This result is somewhat unintuitive if we consider that these rules only give strategies with no exact memory of previous actions.

Two standard types of reinforcement-learning approaches are ► policy search and value-based approaches. The first typically uses gradient methods to move an agent's policy toward a better outcome directly but gradually. That is, if one action currently yields a higher reward than another, then a policy search will play the better action more frequently, and the worse one less. This tenet is the basis for such algorithms as *Infinitesimal Gradient Ascent* (IGA (Singh et al. 2000)) and a variation called *Win-or-Learn-Fast IGA*

(WoLF-IGA (Bowling and Veloso 2001)). The former algorithm achieves a strategy that either converges to or "orbits" the Nash strategy and the latter converges to it consistently, at least in the simplest 2×2 case.

Value-based algorithms keep track of the long-run values of the actions, and use that information to make decisions. Q-learning is a typical example, and it uses the following simple learning rule to adapt action values, sometimes called Q-values, as exponentially weighted moving averages over the obtained rewards. Assuming that the agent perceives only one state, upon getting the reward feedback for an action a, the value update rule is captured by the equation

$$Q(a) = (1 - \alpha)\, Q(a) + \alpha(R(a)),$$

where α is the learning rate and $R(a)$ is the reward received. One variation of Q-learning uses an ε-greedy decision rule, meaning that it explores randomly with probability ε and otherwise takes the action with the highest Q-value: $argmax_a\, Q(a)$. Note that in this simple rule there are two parameters that must be set: the learning rate α and the exploration rate ϵ. As $\alpha \rightarrow 0$, the decision becomes less noisy and more like a continuous-time dynamical system because values are changed smoothly. Even with smoothed learning, the greedy factor means an agent's decision can switch suddenly from one action to the other when the values switch ordering, in contrast to the gradual change of policy-search methods.

Two interacting Q-learning agents form a dynamical system with special properties, called a hybrid dynamical system. In fact, this learning rule creates several dynamical systems that are defined by which actions are greedy. In the 2×2 case, there are at least four distinct systems with separate dynamics. The discontinuous nature of the action decision causes the ε-greedy rule to behave in different ways in the three classes of games described earlier. In general, the learning rule can converge to the Nash equilibrium. However, if there is a non-Nash, cooperative payoff (called ► Pareto optimal) that is higher than the single-play pure Nash equilibrium, then the system enters into an oscillation that yields higher payoffs than a Nash strategy would. Therefore, there are six possible classes of games when agents apply this rule (Wunder et al. 2010).

One example of this oscillatory behavior arises in the so-called Spoiled Child game, described in Table 1. It is a mixed equilibrium game that is not stable for ε-greedy Q-learning. In the game, one player plays the role of a Parent who can `spoil` or `punish`, and the other a Child who can `behave` or `misbehave`. It is better for the Child to be `spoiled`, but the Parent only wants to `spoil` if the Child `behaves`. The Child would prefer to `misbehave` when `spoiled`, so when his Q-values change to reflect this fact, the Parent then will eventually learn to `punish`. Only then will the Child return to behaving, which causes the Parent to `spoil` again. From a pure best-response perspective, it seems like this system of agents would just jump around from one combination of actions to the next. The ε-greedy Q-learning rule tempers this decision making, so that the players spend most of their time in the `spoil/behave` outcome, which is mutually beneficial compared to the Nash outcome.

Consider what happens when two agents play the Prisoner's Dilemma game (Table 2), which has the property that each agent has a dominant action (`defect`) but there is also a mutually beneficial outcome (both `cooperate`) that is significantly higher than both `defecting`. One example of these payoffs would be that Alice pays 1 every time she `cooperates`, but gets 4 if Bob `cooperates`, and vice versa. If the players start out cooperating, ε-greedy Q-learning dictates that their Q-values for `cooperation` rise until they reach value of this action. Eventually, as the players take exploratory actions, the values for `defection` reach this level. Say that Alice starts `defecting` first. She derives some initial benefit for this action, but eventually Bob will begin `defecting` along with cooperating, as his values for both start to

Multiagent Q-Learning Dynamics. Table 1 The Spoiled Child game

	Behave	Misbehave
Spoil	1,2	0,5
Punish	0,1	2,0

Multiagent Q-Learning Dynamics. Table 2 Prisoner's dilemma

	Cooperate	Defect
Cooperate	3,3	0,4
Defect	4,0	1,1

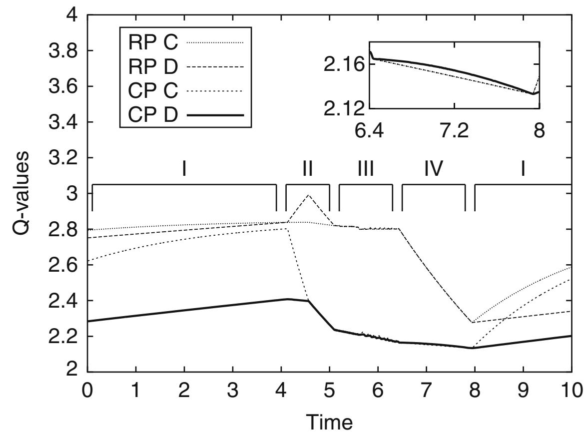
M

fall. Next, Alice's values fall also, but ultimately both players may begin to `cooperate` greedily. At that point, the Q-values return to their higher points, leaving the `defection` values to slowly catch up again. The pattern resembles a Tit-For-Tat sequence, where Alice's `defection` causes Bob to `defect`, even without remembering the previous turn. In effect, the values themselves retain a long-term memory, which stores the benefit of `cooperation` and is not easily erased. This cycle can repeat endlessly, perhaps with one player benefiting slightly more, but with both benefiting more than they would if they both `defected` always. The system has another property in that it does not repeat exactly the same way twice, which suggests a chaotic system. The Prisoner's Dilemma class of games is the only case of the six where chaotic behavior occurs, revealing another unique property of this game to the game-theory community. See Figs. 1 and 2 for a graphical example.

This behavior has a real-life analogy in conflict between groups of people. Imagine two tribes on an island that have specialized skills and resources. One tribe fishes well and the other grows vegetables. Every day, they have the option of giving their extra food to the other tribe, or keeping it for themselves even though it is worth more to the others. Some of the food is eaten while some of it is saved. The two tribes do not keep records of when the other tribe was generous, but keep the food they accumulate in two piles, corresponding to the two actions. Each tribe will take the action that currently has the bigger pile, although occasionally they try the one with the smaller pile. What will happen, considering that on any given day a tribe receives more by keeping its own stock (not giving it away)?

Most of the time the tribes trade normally. Once in a while, one tribe, perhaps the fishing tribe, gets the idea that if they keep all of their fish as well as the vegetables they get from the other tribe they will be better off. However, this action hurts the farming tribe, who begin to provide less produce in response. Over time, the fishers learn that they are worse off than before, and resume trading with the farmers. Notice that this reciprocation is not based on a formal agreement, but instead arises from the dynamics of the decisions over time. In effect, the accumulated value acts as a form of memory regarding each action and its consequences.

The ε-greedy Q-learning rule has a number of properties that distinguish it from other similar rules.

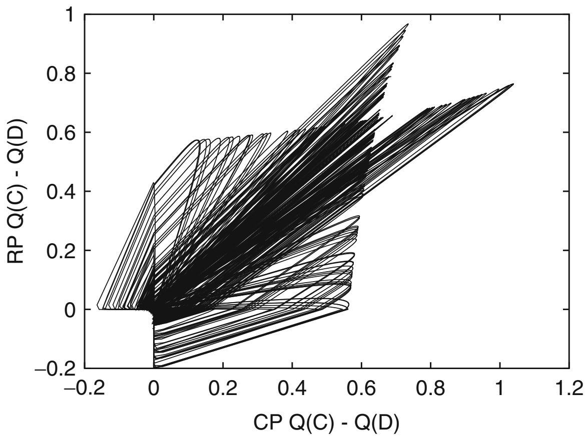


Multiagent Q-Learning Dynamics. Fig. 1 The sequence of four phases during PD with ε-greedy Q-learning agents, as shown by a time series plot of the values for every player's action. Phase I is the peaceful initial phase, where both tribes get along. Phase II occurs when the fishing tribe (RP) learns that it is often better not to give its fish to the farming tribe (CP), so that CP suffers while RP benefits. Phase III is an uneasy period where the tribes cooperate some of the time, but the fishers and farmers give less and less. Eventually the farmers strike back in Phase IV and withhold their produce altogether. After the fishers' food supply drops in value, both sides learn it is better to cooperate and Phase I returns again

Among these are a resilience to undesirable opponent behavior that allows it to guide the outcome to a cooperative one if the opponent is open to it, and defend itself if not. The situations resulting in this non-Nash behavior are limited to those cases where such a cooperative outcome exists, of course. The possibility of chaotic oscillation in a single class of the 2×2 games opens up these learning systems to new areas of analysis. Finally, this analysis demonstrates that there are many feasible approaches when it comes to repeated games that result in outcomes that diverge from a strict focus on discovering one-shot Nash strategies.

Important Scientific Research and Open Questions

This entry discusses the behavior of a specific class of algorithms in a very limited subset of games. The most interesting games have many players, many actions, and may take place in an environment with states. The dynamical system containing Q-learning agents



Multiagent Q-Learning Dynamics. Fig. 2 A figure showing the chaotic behavior of a Q-learning system playing Prisoner's Dilemma, as time progresses. The left axis is the difference of RP's values for cooperate and defect, and the bottom axis is CP's value difference. When the current values cross the zero axis, the behavior changes sharply, and never crossing the same point twice. Because of the chaos, starting with slightly different values leads to greater changes later on

has interesting and unique properties that researchers are just beginning to explore, and an understanding of the simplest games can help others put the investigation in its proper context.

Cross-References

► Learning and Evolutionary Game Theory
► Q-Learning
► Query-Directed Learning

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Multicast

A multicast stream is one-to-many connections between the host and the client's computer, which means that each client receives the same stream of data.

Multicodal Learning

► Multimedia Learning

Multi-Constraint Theory of Analogical Thinking

► Analogical Coherence/Correspondence

Multicultural Education

► Developing Cross-cultural Competence

Multicultural Issues in Music Instruction and Learning

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Synonyms

Cross-cultural issues in music education; Cultural diversity in music education; Cultural issues in music education; Ethnomusicology in education; Intercultural issues in music education; World music education

Definition

Multicultural issues are problems, questions, and topics that arise within the interchange of people of different cultures, or within groups in which more than one ► culture coexists. In education, including the area of music teaching and learning, multicultural issues can arise between learners and instructors of different cultures, among learners in multicultural groups, between learners and culturally incongruent or irrelevant curricula, between instructors and curricula that contain material from a culture different from theirs, and between instructors and the surrounding community if cultural values represented in curricula are different from community values. Issues may also arise when different musical traditions coexist within and across cultures. Multicultural issues specific to music instruction and learning include (a) issues of philosophy, such as the roles of various musical traditions and ► multiculturalism in music teaching and learning, (b) issues associated with the practice of teaching, such as identification of ► best practices and preparation of teachers, and (c) issues associated with people and culture, including the teaching of all types of music to students of all cultures.

Theoretical Background

James A. Banks (1941–), a pioneer in multicultural education in the United States, is a prolific African-American scholar who has developed approaches, theories, principles, and strategies in multicultural education as an action to alleviate racial conflicts and to improve inter-racial understanding. His substantial stream of books and articles began to appear in the 1970s. Many of his books have multiple revisions to date. Some music educators applied elements of his work to music learning contexts with the key dimension of musical-cultural values. Furthermore, knowledge of multicultural issues in music teaching and learning has developed as a result of (a) a desire for music teachers to be effective teachers of all students and to provide equity in music learning environments, (b) the realization that levels of cultural diversity in music learning environments are growing, that culture affects learning, and that learning takes place more easily in culturally relevant environments, and (c) the human desire to make music and learn about music.

Scholarly work on effective teaching provides a plethora of theories and descriptors of effective teaching. Although there is not yet consensus as to a single, widely accepted definition of *effective teaching*, many scholars agree that: (a) All students can learn if taught effectively and (b) Teacher effectiveness is the single most important influence on student learning. Although not referring specifically to the education of ethnically and culturally diverse students, the century-old arguments of John Dewey (1902), in particular, support effective teaching in a way that is congruent with multicultural learning environments. Dewey's theories of effective teaching provide a holistic view of students and curricula, with curricula serving as effective tools, relevant to students' lived experiences, through which students can develop and assert their capabilities without being forced to fracture their ethnic and cultural foundations in the process.

Geneva Gay's (2000) theory of ► culturally responsive teaching, which is defined as "using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them" (p. 29), offered that, in addition to demonstrating qualities generally associated with effective teaching, teachers must also be culturally responsive in order to effectively teach minority students. According to her theory, teachers must demonstrate the following qualities in order to be considered as culturally responsive: (a) a knowledge base of cultural diversity, (b) the ability to design culturally relevant curricula, (c) the ability to incorporate cultural caring in building a learning community, (d) effective cross-cultural communications, and (e) cultural congruity in classroom instruction.

Lastly but not least, "think tanks" of music education philosophers and scholars of different parts of the world contributed substantially to the knowledge base as well. One of the most successful think tanks occurred in 1998, in a Northwestern University (USA) Music Education Leadership Seminar titled *Issues of Multiculturalism in Music Education.* Topics within this seminar included past, present, and future directions of multiculturalism in music education, perspectives on multiculturalism from different parts of the world, philosophical questions on multiculturalism, and applications and practices associated with teaching world musics. The resulting publication in 2002, *World Musics and Music Education* edited by Bennett Reimer, has been pivotal in its importance as a framework for philosophy, research, and practice concerning multicultural issues in music teaching and learning. This publication includes chapters written by some of the most important theorists, practitioners, researchers, and pioneers in this field, such as Bryan Burton, Patricia Campbell, Anthony Palmer, Anthony Seeger, and Terese Volk. Another highly successful think tank is the Cultural Diversity in Music Education (CDIME), which is an informal network promoting exchange of ideas, experiences, and practices. It began in 1992, holding its first conference in Amsterdam. Since then, a biennial conference takes place in different parts of the world. The International Society for Music Education also holds biennial world conferences that contain substantial content materials that address multicultural issues in music instruction and learning.

Important Scientific Research and Open Questions

Although there has been evidence of multicultural music education as far back as a century ago (Volk 1993), the body of research on multicultural issues in music education is hitherto limited, having mainly emerged in the last 20 years. Currently a small, but growing base of knowledge concerning multicultural issues exists in the area of music teaching and learning. As a result of scholarship in this area, several important questions have been highlighted relating to the role of world musics in school curricula, preparation of teachers for multiculturalism, and the actual teaching of multicultural music.

The Role of World Musics in School Music Curricula

A majority of music education practitioners and scholars agree that a well-rounded music education includes the study of world musics. However, this idea does not always translate into practice in school music. Music curricula in many schools still include music from only a few traditions, usually predominated by the Western-art-based tradition. The question remains as to how to translate beliefs supporting the value of world musics into more widespread inclusion in school music curricula.

Currently, the purpose of world musics within school curricula is somewhat mixed. Some music educators and music education scholars support the view that the role of world musics is to serve as a vehicle for student learning of musical concepts, as well as a means of learning about musical traditions found in different parts of the world. Others believe the role of world musics is to facilitate the development of multicultural understanding, by helping students develop cultural identity, respect, and appreciation, and by preparing them to be members of an increasingly global society. Still others believe the role of world musics is dual, and that the goal is to accomplish both of these. Until the role of world musics in schools is further clarified, questions will continue to arise as to what best practices should be for teaching it.

Preparation of Teachers for Multiculturalism in Music Learning Environments

Music educators and scholars would agree that everyone has culture, that culture affects learning, and that some students exhibit identifiable cultural learning styles. Cultural differences can cause difficulties for music teachers in designing instruction that is relevant to students of different cultures. In addition, there is a general consensus that these difficulties, in part, lead to a higher rate of teacher attrition in schools having culturally diverse student populations, and that music teachers often feel unprepared by their teacher-training programs to be effective in culturally diverse learning environments.

Research has shown that extended social interaction between music teachers and students of differing cultures aids in the development of cultural appreciation and respect in music learning environments, increases music teachers' comfort levels in working with culturally diverse populations of students, and increases their willingness to teach in culturally diverse learning environments. In addition, research has shown that in order for students of minority cultures to learn, it is critical for music teachers to become culturally responsive in their teaching, including acquisition of in-depth knowledge of students and their cultures, design of instruction that incorporates students' prior experiences, and facilitation of a caring, supportive classroom environment (Lehmberg 2009). Extended pre-service field experience has been shown to be helpful in raising pre-service music teachers' levels of comfort in culturally diverse learning environments (Emmanuel 2006).

Although research has shown that extended social interaction between teachers and students of minority cultures has increased teachers' comfort levels in multicultural learning environments, it has not definitively shown that this type of experience actually increases teacher effectiveness in these types of environments. Hence, the question remains open as to how music teachers can best be prepared not only to be comfortable in multicultural environments, but also to be effective teachers of culturally diverse populations. Many music education practitioners and scholars feel that music teacher-preparation programs should shoulder the responsibility of preparing music teachers to be culturally responsive in multicultural learning environments. An inherent issue is that music teacher educators often have little or no experience themselves in culturally diverse learning environments, making it difficult for them to effectively mentor students as to best practices for teaching and learning in these types of environments. The music education profession has not yet discovered a solution to this problem.

Issues Concerned with the Teaching of World Musics

Issues also exist surrounding the best teaching practices for world musics. One of the largest concerns among music educators is the ► authenticity with which world musics are presented in various music learning environments. The general consensus within the area of music teaching and learning is that world musics should be presented authentically; yet, a great deal of controversy exists concerning the level of authenticity. Some feel that authenticity should be absolute or near-absolute, meaning that world musics should be (a) presented by a ► culture-bearer, (b) set within their cultural context, (c) presented in their original languages, and (d) culturally appropriate within the context in which they are presented. Others encourage teachers to include world musics in instruction even if no culture-bearer is accessible, but to take great care that the presentation is accurately situated in its culture, contains original lyrics and notation (where utilized), and above all, is "faithful to the nature of the musics involved" (Fung 2002, p. 201). Still others believe that authenticity is a continuum, and that it is appropriate for the degree of authenticity to fluctuate depending on the age of the students involved, as well as issues that might arise from the original language of the music and students who are speakers of a different language. For example, some practitioners feel that it is appropriate to change elements of a piece of music (lyrics, rhythms, etc.) in order to accommodate students who have not yet attained the level of musical development necessary to perform the piece authentically. Their rationale is that it is more important to include the piece in the curriculum and present it in a pseudo-authentic manner, than to leave the piece out of the curriculum completely. In addition, if the original lyrics of a piece of multicultural music contain a word or words that are homonyms of words in the students' language that are inappropriate in a music learning environment, some practitioners feel that it is appropriate to change those words in order to keep the students' focus on the piece as a whole.

A second, perhaps less controversial issue concerns preparation of teachers with the knowledge and skills they need to teach music of many cultures. Similar to the prevailing attitudes concerning preparation of teachers to be effective with culturally diverse groups, many music education practitioners and scholars feel that the responsibility of preparing teachers to teach world musics should fall on teacher educators within music teacher-preparation programs. Questions associated with this include the determination of (a) which teacher education courses should include the study of world musics and their pedagogies and (b) how to fit instruction on world musics and pedagogy into already-packed music teacher preparation programs.

Cross-References

► Authenticity in Learning Activities and Settings
► Cross-Cultural Factors in Learning and Motivation
► Cross-Cultural Learning Styles
► Cross-Cultural Studies on Learning and Motivation
► Cross-Cultural Training
► Developing Cross-Cultural Competence
► Intercultural Learning
► International Perspectives in Music Instruction and Learning
► Music and Learning

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Multiculturalism

The practice of accepting, promoting all cultures in society; providing equal opportunity and equity for all cultures in society.

Multidisciplinary Learning

► Concept Similarity in Multidisciplinary Learning

Multidisciplinary Research on Learning

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Synonyms

Cross-disciplinary research on learning; Interdisciplinary research; Transdisciplinary research

Definition

Multidisciplinary research refers to how two or more disciplines contribute to understanding and defining what learning is. Parallel concepts, or cousins, as some researchers (e.g., Strober 2011) describe them, are cross-disciplinary, interdisciplinary, and transdisciplinary. They illustrate the depth of the integration of disciplines. Very often, multidisciplinary and cross-disciplinary are used as synonyms describing the aim to *cross* boundaries between disciplines, e.g., in research questions and methodological approaches of learning. Interdisciplinarity aims at a deeper integration of methodologies, theories, contents, and perspectives. *Inter*action raises new research topics, creates new concepts, and expands and deepens research questions. Transdisciplinarity denotes even greater level of integration by *trans*ferring and transcending, e.g., knowledge and research methods to joint learning, research tasks and creates a unity of knowledge in the most radical sense without any boundaries between disciplines. We can find a wide range of definitions of these concepts, and the divisions between the definitions are not always obvious. A multidisciplinary research project on learning can have elements of all these definitions.

Theoretical Background

Traditionally, learning research has had a home in psychology. However, it has had also a close relationship with the educational sciences, particularly educational psychology. In the last three decades, the focus has moved from teaching to learning research in the educational sciences (Niemi 2009). Different subject matters in schools, e.g., math, science, and languages, are studied more and more from the learner's perspective, which connects psychology, education, and a large range of academic disciplines. In the last two decades, the spectrum has widened radically, and, presently, a wide range of disciplines contribute to the understanding of learning. Learning has become a concept that is situated in the contexts of different disciplines. In addition to education and psychology, it is an important concept in sociology, economics, technology, architecture, and neuroscience, among other disciplines.

The major reasons for multidisciplinarity are changes that have happened at conceptual levels or methodological issues related to learning phenomena and urgent needs in society.

Changes in the Concept of Learning: Cognition and Learning as a Social Process

The concept of learning has gone through a large process of redefinition in recent decades. Learning is seen more and more as an active individual process, where learners construct their own knowledge base (constructivism). Learning is also increasingly seen as a process based on sharing and participation with different partners in a community, and is being viewed as a holistic process of construction interconnected with learners' social and cultural premises. Social perspective theories have been variously called social constructivism, the sociocultural perspective, sociohistorical theory, and sociocultural-historical psychology. Although social perspective theorists' views are diverse, each theorist posits that learning occurs through the mediation of social interaction. Knowledge is not an individual possession but is socially shared and emerges from participation in social activities (Cole 1991; Reynolds et al. 1996, p. 98).

The concept of cognition emerged in the 1970s in learning research. Related to it, the concepts “metacognition” and “self-regulated learning” have changed the landscape of learning. Even though learning is seen as a social process, there are many research topics concerned with the individual level. We have evidence that self-regulated learners are generally characterized as active learners who efficiently manage their own learning experiences in many different ways. Self-regulated learners have a large arsenal of cognitive and metacognitive strategies that they readily deploy, when necessary, to accomplish academic tasks. Many researchers stress that motivational and emotional strategies have a very important role in self-regulated learning processes. Paul Pintrich (2000) defines self-regulated learning as the strategies that students use to regulate their cognition as well as the resource management strategies that they use to control their learning.

The concepts of cognition and socio-constructivistic theories have opened many channels for cooperation with other disciplines. The questions of lifelong learning as well as inclusion and exclusion in society and different communities connect learning research with education, social science and sociology, cognitive science, and recently and with increasing frequency, neuroscience. New topics in neuroscience include, e.g., how people learn empathy and how we can find changes in their brain. Important cross-disciplinary research areas connecting the social nature of learning and cognition can be found in organizational learning. Organizational learning is enabled through an increased awareness of distributed cognition and emotions. It can be seen as the evolution of consciousness; organizations are the places where the circumstances for this evolution are created. Leaders play a key role in enabling these circumstances.

Changes in the Concept of Knowledge

The concept of knowledge has also changed from one of static transmitted contents to knowledge that is ever renewable and often construed jointly with other learners. Knowledge creation is socially shared and emerges from participation in sociocultural activities. The contents and processes are intermediating. No longer does any one institution or group have a monopoly on knowledge. While knowledge continues to be available in educational institutions such as schools and universities, it is increasingly located in workplaces as well as in everyday life, accessible through various media- and technology-based environments. Open access to knowledge creates new requirements for learners and learning research.

Learning Environments Have Changed Radically

Along with schools and educational institutions, they now also cover a large range of different kinds of learning spaces, including virtual environments. Working life and organizations as well as the media and leisure time are tearing down traditional concepts of where and how people are learning. People can learn even if there is no teaching provided, and it is well known that some people do not learn when teaching *is* available. Learning environments have also changed because of development and the impact of technology. New tools of digital and mobile technology, web-based communication, technology-supported collaborative learning environments, human–computer interaction, and learning machines have opened rich research areas for promoting learning. Social media connected with these new tools create globally shared platforms of learning.

Learning, the Brain, and the Mind

Findings from recent research on the brain provide new knowledge on how brains learn throughout life. The new findings about the plasticity of the brain and the importance of learning environments for the brain, e.g., the quality of the social environment and interaction, nutrition, physical exercise, and sleep, call for more multidisciplinary research and more holistic approaches than ever before.

The OECD’s (the Organization for Economic Cooperation and Development) Centre for Educational Research and Innovation (CERI 2007) has recently published the comprehensive book *Understanding the Brain: the birth of a learning science.* It begins, “After 2 decades of pioneering work in brain research, the education community has started to realize that ‘understanding the brain’ can help to open new pathways to improve educational research, policy and practice” (CERI 2007, p. 13). The publication is a compendium of the recent state of the art in brain research and cognitive neuroscience. One of the main messages is that understanding human development from the perspective of neuroscience could have a powerful impact on educational practice. Even though we do not yet have the answers to all learning problems, we have significant scenarios about how our brain works in learning processes and how we can utilize this knowledge. New methods in the neurosciences which allow measurements in more natural conditions are promising and will create important connections between biological, neural, philosophical, psychological, and social processes of learning. Research in neuroscience has acted as an eye opener to the world of consciousness. It relates many questions to the mind and how we create and use our minds when steering our behavior. Philosophy is also needed in these themes.

Learning Has Become a Societal and Political Concept

Knowledge-based societies want to base their future on people's capacities to learn. Learning across the lifespan is a typical topic when speaking about changing occupations and aging issues, which are examples of why learning should be a continuous process throughout life. Changes in society and the nature of work, competence building, knowledge management, social innovations, access to learning, and issues of inclusion and exclusion urgently highlight the need for multidisciplinary learning research. We know that learning experiences shape learners' own learning identity, and that learning has many connections with quality of life, even with health and personal well-being. Learning can be seen as empowerment. This means that through learning, people acquire the tools to shape and control their lives and can create new knowledge and competencies. Learning across the lifespan means that educational systems, formal and nonformal settings of learning, and informal learning, including tacit knowledge have became important research areas.

Important Scientific Research and Open Questions

In order to activate multidisciplinary learning research, some countries have open national research programs (OECD 2007). Great Britain had the extensive national program TLRP (Teaching and Learning Research Program) in 2003–2008, which continued with an extension on technology until 2010. Finland has the Life as Learning Program 2002–2006 promoting multidisciplinary research on learning. National initiatives have been also taken in Sweden, Norway, and other European countries. Another action has been the establishment of research centers in universities that cross disciplinary borders. Almost all the best universities have centers or research programs that focus on issues of innovative uses of technologies and new media. In many cases, commercial interests are also involved. Many business schools have centers for organizational learning and even connections to the neurosciences, e.g., in decision making. Finally, national or international cross-disciplinary networks have been established. Many of them are related to technology-based learning environments or lifelong learning, and some have a larger umbrella (e.g., the CICERO Learning Network, www.cicero.fi/sivut2/) connecting research on learning, the brain, and technology.

We can see many indications that a multidisciplinary research on learning, and even interdisciplinary cooperation, is on the rise. Research incorporating transdisciplinary approaches is still very rare, due to funding issues and universities' administrative structures. Strober (2011) sees that even stronger barriers are cultural. Talking across disciplines is as difficult as talking to someone from another culture. Different disciplines have their own disciplinary languages and their own assumptions, concepts, categories, and methods of discerning, evaluating, and reporting. They also differ in styles of arguing. Multidisciplinary research on learning is still a very young phenomenon. There are many indications that interdisciplinary research is slowly increasing in areas where there has long been continued cooperation, such as technology- and media-based learning environments. David Sill (2001) argues that that integrating interdisciplinary work should be seen more as a process than an outcome. This is relevant also in learning research. Seeking more cooperation and even integration opens our eyes to the complexity of learning phenomena and provides new tools to investigate them in a holistic way. When emphasizing learning as a very complex phenomenon, at the same time we must see that contexts in our societies are even more complex. Seeking solutions to complex problems requires insights from multiple disciplines. The diversity of disciplinary knowledge, perspectives, and methods is a source of creativity. And it is this creativity that we urgently need if we consider learning as the main factor in empowering people in their own lives and regard learning as a primary tool for a knowledge-based economy and society.

Cross-References

- ► Field Research on Learning
- ► Learning Environment(s)
- ► Longitudinal Research on Learning
- ► Metacognition and Learning
- ► Metapatterns for Research into Complex Systems of Learning
- ► Neuroeducational Approaches on Learning

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Multifaceted Model of Intrinsic Motivation

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Synonyms

Intrinsic reward system

Definition

Intrinsic motivation refers to motivation that comes from inside an individual rather than from any external or outside rewards.

Theoretical Background

What are the basic desires of our species? What moves us? Are there universal goals common to our species?

Global theorists reduce all human motives to only two or three kinds. Mind-body dualists, for example, divide motives into just two kinds, the needs of the soul versus the needs of the body. Hedonists distinguish between positive and negative feelings. Freud reduced all human motives to sex and aggression. Social psychologists classify motives into two global categories called intrinsic versus extrinsic motivation.

In contrast, multifaceted theorists recognize that goals are too diverse to reduce them into two or three macro categories. They delineated anywhere from 5 to 30 fundamental motives, many with different evolutionary histories. Multifaceted theorists say that human motives cannot be validly classified into just two categories such as intrinsic and extrinsic motivation (Reiss 2005).

Four generations of Harvard University psychologists – William James, William McDougall, Henry Murray, and David McClelland, plus Abraham Maslow – advanced multifaceted theories of human motives. William McDougall (1908) suggested that every person is so constituted to seek, strive for, and desire the same goals. These universal goals include food, romantic intimacy, companionship, shelter from danger, and triumph over opponents. Both James and McDougall called these goals "instincts" because they are desired automatically and not the result of conscious reflection. Henry Murray called them "psychological needs." To give emphasis to the subjective aspects of these instincts/needs, I called them "basic desires."

Multifaceted theories were quite popular during the first 60 years of the twentieth century, but they eventually lost influence. The Harvard psychologists did not scientifically validate their lists of needs. Further, the Harvard psychologists and many of their followers based nearly all of their research on controversial (and arguably imprecise) projective measures of the unconscious mind. When scientists challenged these measures in the 1960s and 1970s, research on human needs rapidly lost its influence because of the absence of a noncontroversial measure. Another issue concerned the relevance of human needs theories. The Harvard psychologists and their followers applied their motives to what are now outdated models of psychiatric diagnosis and to little else. Without practical applications to issues beyond clinical diagnoses, social science moved back to global models of motivation, especially intrinsic versus extrinsic motivation.

In the early 1990s, I had a novel idea: If we want to learn what are the true fundamental wants of human nature, why not ask people? I was aware that many psychologists believed that what people say about themselves can be unreliable and self-serving, but I modified our research methods to minimize these distortions. Susan Havercamp, at the time a graduate student, and I conducted a series of surveys that asked people from diverse stations in life to tell us, anonymously, what they desired (Reiss and Havercamp 1998). Using mathematical techniques called exploratory and confirmatory factor analysis, we identified the following 16 basic desires:

Acceptance, the desire for positive self-regard
Curiosity, the desire for understanding
Eating, the desire for food
Family, the desire for family life
Honor, the desire for character
Idealism, the desire for social justice
Independence, the desire for self-reliance
Order, the desire for orderliness
Physical activity, the desire for muscle exercise
Power, the desire for influence
Romance, the desire for sex
Saving, the desire for collections
Social contact, the desire for peer companionship
Status, the desire for high social standing
Tranquility, the desire for safety
Vengeance, the desire for confrontation

All psychologically important human motives appear to be expressions of these 16 or combinations of these 16 basic desires (Reiss 2004).

Important Scientific Research and Open Questions

I constructed the Reiss Motivation Profile (RMP), a self-report instrument, to assess the strength and weakness of each of the 16 basic desires. The RMP has been validated scientifically in terms of what are called "construct validity" (which shows mathematically how each motive is associated with other motives), reliability (which shows that a person's basic desires are stable over time), and criterion validity (Havercamp and Reiss 2004). Using the RMP, we can assess the following six common motivational causes of poor grades in schools, each with a different implication for intervention.

Afraid of Failure (*High Need for Acceptance*). Nobody likes to fail, but most people can shrug off the experience and move on. A small percentage of students, however, experience failure as devastating. Since failure hurts less when they do not try, students who are devastated by failure tend to underachieve because they hold back effort. Parents and teachers should gently encourage them to improve effort and grades.

Incurious (*Low Curiosity*). Students vary enormously in how long they can sustain thought before they scream in frustration. Students who hate to think are naturally incurious with regard to book learning. These students tend to be bored with intellectual activities, theories, and abstractions. Parents and teachers need to use extrinsic incentives with these students. Since deep thinking is not required in many careers, these students may achieve much more in life than in school.

Laid Back (*Low Desire for Power*). Students who devalue achievement tend to be laid back and interested in leisure. These students do poorly in school because they do not care about doing well. They will have a tendency to underachieve in school and later in career. Parents and teachers need to set strict expectations and provide extrinsic incentives to motivate learning.

Disorganized (*Low Desire for Order*). Some students experience order as confining and prefer to follow their nose. These students tend to be disorganized. Some teachers mark them down for being sloppy. Parents and teachers should teach organizing skills to help these students.

Combative (*High Desire for Vengeance*). Some students may do poorly in school because they are distracted by their battles. Parents and teachers need to help these students learn how to direct their fighting spirit into socially appropriate activities such as competitive business or perhaps sports.

Expedient (*Low Desire for Honor*). These students may shirk duties such as homework when they think they can get away with it, or they may cheat on exams when they think the teacher is not watching. Teachers mark these students down for being irresponsible. Parents and teachers need to set strict ethical limits with these students.

Cross-References

- ► Academic Motivation
- ► Curiosity and Exploration
- ► Interest and Learning
- ► Interest-Based Child Participation in Everyday Learning
- ► Motivation to Learn: Modern Theories
- ► Motivation, Volition, and Performance
- ► Stability and Change in Interest Development

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Multilayer Investigations

A multilayer analysis is a procedure which interrelates data from different levels of social reality in order to explain individual and collective data with regard to effects of social groups, organizations, societal subsystems, learner characteristics etc. on individual behaviors and achievements.

Multilayered Context

Multilayered context represents spatial context and hierarchical context. In general, a scene consists of multiple objects in a background. These visual elements are not independent but contextually interrelated. The spatial context can be part–part context and object–object context. The hierarchical context can be part–object context and object–background context.

Multimedia

Multimedia means a combination of different media. Multimedia includes a combination of text, audio, still images, animation, video, and other form of interactivity content.

Cross-References

- ► Streaming Media
- ► Video-Based Learning

Multimedia CALL

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Synonyms

Language learning through multimedia; Multimedia enhanced language learning; Multimedia language learning

Definition

Multimedia CALL refers to the learning of a (primarily second or foreign) language supported by multimedia technology. Multimedia for language learning covers a wide range of visually and/or aurally enhanced instructional materials, from audio recordings, picture flash cards, graphically annotated texts, and subtitled television broadcasts to interactive educational software applications such as ► courseware, interactive videodisks, and ► digital games.

Multimedia CALL is generally used in a broader sense than ► multimedia learning, as the latter refers specifically to learning with pictures (including video) and sound, and as its research focuses on the effects of the characteristics of aural and visual materials on learning. Multimedia CALL also encompasses non-sensory aspects that are central, though not exclusive, to multimedia applications, such as interactivity, learner control, and motivation. From a technological and pedagogical point of view, multimedia CALL is more restricted than *multimodal (computer-assisted) language learning*, which denotes learning by means of multimedia applications that make use of several *modes* of bidirectional human–machine interfacing, such as typed text, speech, gestures, and facial expressions. In multimedia applications, pictures, sound, and text are only situated at the level of the material, not on the level of learner output, which is limited to typed text or clicking.

Multimedia CALL is a significant area of interest in the field of Computer-Assisted Language Learning (CALL). This field also investigates, among other aspects, the affordances of computer-mediated communication (CMC), artificial intelligence (natural language generation and parsing), and corpora for language teaching and learning.

Theoretical Background

A useful theoretical framework for multimedia CALL is based on the ► Cognitive Theory of Multimedia Learning, and is expanded in the light of interactionist second language acquisition (SLA) theory (Chapelle 1998). The basic assumption of CTML is that the human brain is equipped with a visual/pictorial as well as a verbal/aural channel for processing information, that these channels function independently of each other, and that learning will be most effective when both channels are simultaneously stimulated.

Interactionist theory of SLA is grounded in a perspective that puts meaningful, communication-directed interaction in the second language (L2) center-stage, rather than discrete, form-focused teaching of grammar and vocabulary. Attention to formal aspects of an L2, such as phonological, lexical, morphosyntactic, or pragmatic structures, is both incidental and inherently part of the ongoing interaction. Interactionist theory of SLA defines three aspects that are crucial to second language acquisition: comprehensible input, interaction, and comprehensible output. *Comprehensible input* is that portion of all the L2 input to which the learner is exposed that is just above his or her proficiency level, in which case the learner is more likely to notice aspects of the L2 (such as new vocabulary or grammatical structures), which may then become candidates for intake into the learner's linguistic system. *Comprehensible output* is the part of the output produced by the learner that can be comprehended by other users of the language or, in the case of multimedia learning, a computer application. *Interaction* encompasses the meaningful exchanges between the learner and teacher, native speaker(s) and peers through technology, as well as between the learner and technology. Exchanges are considered meaningful when they lead to comprehensible input, or to linguistically correct or appropriate comprehensible output. This mirrors the communicative process in which speakers of the L2 cooperatively try to work out or clarify the meaning of words, chunks, or sentences.

The function of multimedia, then, is to enhance the SLA process by supporting comprehensible input, and by eliciting and negotiating comprehensible output through interaction. More specifically, multimedia is thought to play a significant role in the apperception (selection), comprehension (organizing), and intake (integration) of input. Moreover, it is considered to facilitate (learner) correction of erroneous or incomprehensible output.

Apperception is the selective process in which a share of all the verbal and pictorial input given to the learner is respectively represented in a verbal text base and in a visual image base. This process involves *noticing*, that is, selectively and consciously focusing one's attention on specific aspects of the L2 input that are not yet acquired. The role of multimedia in apperception is to visually and/or aurally enhance the input, and to increase the chances that learners are prompted to notice important aspects of the language. Typical input enhancement strategies are lexical or grammatical highlighting, displaying pictures for certain words, and adding video to aural material.

The next step toward language acquisition is *comprehension*. In this process, material in the verbal and visual bases is organized into verbal and visual models. These models imply understanding of the semantics of the L2 and also, to some extent, syntactical aspects.

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The process of comprehension is thought to be mainly catalyzed by the interactive features of multimedia applications. When learners are given control over the input which they are exposed to, they can decide which portions need to be modified in order to be made comprehensible, for example, by means of pictures or aural information. Receiving these tailored input modifications is thought to facilitate the SLA process significantly.

Subsequently, in the cognitive process of *integration*, connections are established between verbal and visual mental models. For SLA, this means that the *intake*, or the comprehended input that can potentially be acquired, becomes part of the learner's linguistic system. This phase relies heavily on the retrieval and activation of prior knowledge, with which new information is integrated. Prior knowledge can be stimulated and retrieved by so-called *advance organizers*, which serve as introductory material to new information. Typical advance organizers in the form of multimedia are video passages.

In SLA theory, there is growing consensus that (comprehensible) output plays a significant role in the acquisition process. Output is considered to serve acquisition, because it gives learners the opportunity to test their knowledge of the L2 by getting (corrective) feedback from other L2 speakers, and to modify and correct their output in case of problems. It should be kept in mind that in multimedia environments, technology mediates the ways in which (comprehensible) output is realized, so that output may comprise either of genuine and (relatively) free L2 production, such as typed text and speech, or of more limited kinds of output, such as pointing and clicking.

Important Scientific Research and Open Questions

Research in multimedia CALL has principally examined the effects of multimedia on L2 vocabulary acquisition, reading, and, to a more limited extent, listening comprehension. Only a small number of studies have dealt with the role of multimedia for stimulating productive language skills, and with individual differences, such as the role of learner control in multimedia environments, and the impact of multimedia on learner attitudes.

There are consistent findings that lexical items accompanied by pictures lead to better intentional as well as incidental L2 vocabulary acquisition than lexical items without pictorial enhancement. Picture glosses in reading texts help vocabulary acquisition more than textual glosses. Moreover, research on incidental vocabulary acquisition in reading texts (e.g., Plass et al. 1998) indicates that learners profit more when they look up both textual and pictorial annotations than when they look up only one type of annotation. Next, highlighting of words in reading texts does not in itself facilitate incidental vocabulary acquisition, but highlighting with multimedia glosses has been shown to be effective (e.g., Chun and Plass 1996).

In the area of vocabulary learning, more research is warranted into what types of pictorial information facilitate acquisition better than others, for example, high-imagery words (i.e., words that can be easily depicted in images) vs. low-imagery words, or moving video vs. still images.

Most of the findings in the area of vocabulary acquisition can be extrapolated to the development of L2 reading skills. There is large empirical support that the apperception process in reading activity profits from the highlighting of words in conjunction with the provision of multimedia glosses. Next, reading comprehension benefits more from the provision of picture glosses than from textual glosses. In addition, text comprehension is aided when learners look up both pictorial and textual annotations than when they only look up one type of annotation. A particular strategy based on multimedia that improves text comprehension is the inclusion of advance organizers in the form of video (Plass et al. 1998).

Listening comprehension seems to be aided by the use of video, especially for learners with high spatial ability. Also, pictorial and textual enhancements of listening materials enhance text comprehension, and pictorial annotations in particular have a strong and lasting effect on text comprehension. In addition, even if the combination of pictorial and textual enhancements leads to better immediate results, learners tend to prefer to choose which type of enhancement they get, depending on the situation.

Little research to date has investigated the effects of multimedia on learners' realization of (comprehensible) output in communication-oriented instructional approaches. As for the impact of multimedia on learners' language production, one recent experimental study found that learners produce significantly more on-task chat language and negotiation strategies in 3D than in text-based immersive virtual environments (Bumgarner 2008). More research in the area of digital game-based language learning may empirically investigate the effects of sound, text, and animation (animated pedagogical agents) on the language learner's output. Moreover, for many meaningful pedagogical tasks, graphical aspects of the immersive environment may not be crucial, which allows for experimental comparison.

Given recent technological advancements in the area of speech technology and natural language processing for language learning, and considering the strong tendency in SLA theory to revalue pushed output and corrective feedback for learning, more research is expected into the role of multimedia for providing valuable feedback and for stimulating comprehensible output. Multimedia may play a significant role in enhancing the feedback on productive activities. As an example, claims have been made for including visualized feedback in courseware for speaking practice, in order to help language learners correct pronunciation errors.

Learner control in multimedia applications remains a controversial issue, but there is tentative support that learners benefit more when they can control the order of instruction, its pace, and the availability of help options. Learner attitudes toward multimedia CALL are, as may be expected, generally favorable (Brett 1996).

Research on multimedia CALL has important consequences for language pedagogy and instructional design. From a pedagogical point of view, interest in multimedia applications is largely motivated by claims for realizing authenticity in task-based environments. However, rather than just taking the value of multimedia applications for language learning for granted, language educators should be (made) aware of the general findings established in multimedia CALL research, so that they can make objective judgments over instructional materials and technologies. Second, findings in multimedia CALL research should be taken into account when designing instructional software and learning environments.

Cross-References

► Advance Organizers
► Game-Based Learning
► Language Acquisition and Development
► Language Learning
► Multimedia Learning
► Multimodal Learning
► Psycholinguistics and Learning
► Second Language Learning
► Vocabulary Learning in a Second Language

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Multimedia Enhanced Language Learning

► Multimedia CALL

Multimedia Information

► Animation and Learning

Multimedia Language Learning

► Multimedia CALL

Multimedia Learning

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Synonyms

Audio-visual learning (older); Multicodal learning; Multimodal learning

Definition

Multimedia learning refers to situations in which people learn from words and pictures; also optionally, using other modes, such as haptic devices, smells, or tastes. As the latter are rather seldom used, research on multimedia learning refers almost exclusively to learning with texts and pictures. Texts comprise material that is presented in verbal form and include printed and spoken words. Pictures refer to the pictorial form and include static pictures, such as graphics, diagrams, illustrations, photos, and maps, as well as dynamic pictures, such as animations, films, or videos.

The term "multimedia" in its current definition emerged at the end of the 1980s and was adapted from marketing into educational psychology. Even so, there are three different approaches to what is meant by "multimedia": first, it is the delivery device used to display the information, such as a computer screen, a blackboard, speakers, or a flipchart. Second, it is the presentation modes or representational formats that are applied to present the information, such as using words or pictures. Third, it is the sensory modalities used by the learners to receive the information, such as eyes and ears. Whereas the first definition represents a technology-centered approach, the latter two represent a learner-centered approach. The technology-centered approach may be of importance in practice, but is not sufficient from a psychological point of view as it is not crucial for learning whether information is presented in a book or on a computer screen. Therefore, research on multimedia learning refers to the learner-centered approach. In order to obtain conceptual clarity in the learner-centered approach, some authors differentiate *multicodal* learning and *multimodal* learning: *multicodal* implies the use of different codes, such as phonemes, letters, signs, symbols, etc., (representational formats view). *Multimodal* refers to the use of different sensory modalities, such as visual, auditory, haptic, or olfactory (sensory modalities view). The most frequently used definition of multimedia learning as learning from words and pictures is based on the representational formats view (Mayer 2009).

As the term "multimedia" is mostly associated with the information presentation by digital media, some authors also see *interactivity* as an essential attribute of multimedia learning. In contrast to multimedia, however, interactivity is a reciprocal activity between a learner and a learning system and therefore requires behavioral activities on the learner's side. While both multimedia and interactivity seek to cognitively engage the learner, behavioral activities of the learner are a defining feature of any interactive event (Domagk et al. 2010).

Theoretical Background

Following this definition, multimedia learning as a phenomenon has existed since instructional pictures were first used together with verbal explanations.

Two theoretical approaches have mainly influenced current models and theories on multimedia learning: Paivio's "dual code" theory of human cognition (assumption of separate channels for processing visual and auditory information), and Baddeley's model of the human working memory with an emphasis on the limitation of the amount of information that can be processed in each channel at any one time (Paivio 1986; Baddeley 1986). Based on these approaches, Mayer developed a *cognitive theory of multimedia learning* (CTML, Mayer 2005, 2009). A third assumption besides dual channels and the limited capacity of the working memory is an *active processing* of information covering the selection, the organization, and the integration of the processed information into coherent mental representations.

Figure 1 represents the main features of the CTML. Words (written or spoken) and pictures from a *multimedia presentation* (far left box) reach the sensory memory (ears or eyes) where they are held for very short periods. *Selected* information is then transferred to *working memory*, a *capacity limited* functional system representing the temporarily holding and manipulating of information at least partly in active consciousness. Information from both sensory modalities (visual, auditory) are processed and *organized*, sound images are related to pictorial images and vice versa. The sound of a word (e.g., the word "dog") is related to an image of a dog and the visual image of a dog is related to the word "dog," constructing *verbal and pictorial models*, which are related to and *integrated* with elements of prior knowledge. In Fig. 1, prior knowledge is represented by the far right box labeled *long-term memory.*

In accordance with dual-code theory (Paivio 1986), separate channels are assumed for the processing of verbal and pictorial knowledge. The limited capacity assumption, based on Baddeley's model of the human working memory (Baddeley 1986), means that each channel has limited processing capacity. One corollary is the assumption that the total amount of information to reach working memory can be greater if both channels are used instead of only one.

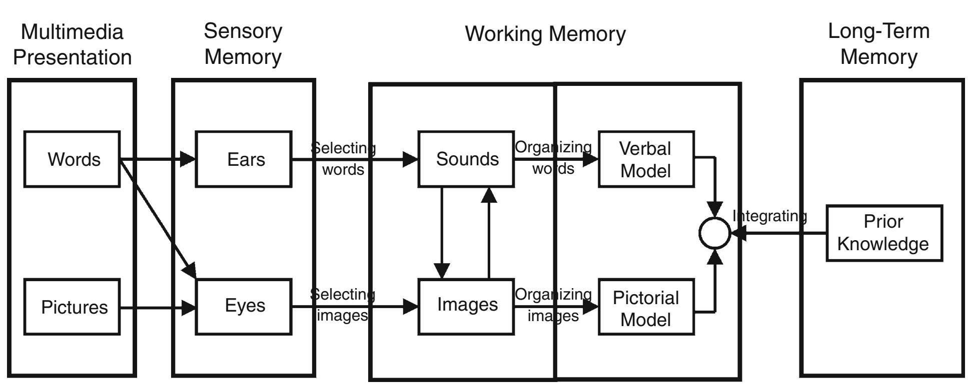
The cognitive theory of multimedia learning claims to be a theory functional for the instructional design of multimedia learning environments and applied sciences of learning, but not for cognitive science or neuropsychology. Empirical research to prove the theory, therefore, mostly refers to applications in instructional design.

An alternative model for multimedia learning is the *integrated model of text and picture comprehension* (Schnotz 2005). Both models consistently assume multiple memory systems in the human cognitive architecture including a limited-capacity working memory and, in accordance with dual-code theory (Paivio 1986), different channels for information processing and storage. The main difference between the models is that the cognitive theory of multimedia learning assumes that a verbal model as well as a pictorial model are constructed and then integrated. In Fig. 1, the integration is represented by the circle in working memory. The integrated model of text and picture comprehension, however, assumes the construction of only one mental model that integrates the information from auditive and visual working memory, as well as the propositional representations.

Another theoretical approach that mainly influenced research on multimedia learning is *cognitive load theory* (Chandler and Sweller 1991). It describes multimedia learning and instruction in terms of efficiency considering the cognitive load that is imposed by additional representations of information (adding words or pictures) or the instructional design of the learning material. The cognitive costs are conceptualized by three kinds of cognitive load in working memory: (1) essential (intrinsic) cognitive load, which depends on the number and interaction of the elements of a learning task; (2) extraneous cognitive load, which stems from sources outside the core of the learning task (irrelevant information, bad instructional design, bad usability, background sounds, etc.,); and (3) generative (germane) cognitive load, which is needed for the elaborative and constructive processing of the information in working memory.

Important Scientific Research and Open Questions

A series of experimental studies confirmed hypotheses deducted from the cognitive theory of multimedia learning, and the integrated model of text and picture comprehension, as well as Sweller's theory of cognitive



Multimedia Learning. Fig. 1 Cognitive theory of multimedia learning (From Mayer 2009, p. 61) load. Mayer (2009) summarizes the results of these experiments in 12 principles grouped into three categories: principles (a) for reducing extraneous processing, (b) for managing essential processing in multimedia learning, and (c) for fostering generative processing in multimedia learning.

- Principles for reducing extraneous processing in multimedia learning.
  - *Coherence principle*: learning is improved when (1) interesting but irrelevant words and pictures (seductive details), (2) interesting but irrelevant sounds and music, and (3) unneeded words and symbols are excluded or removed from a multimedia presentation.
  - *Signalling principle*: people learn better when cues that highlight the organization of the essential material are added.
  - *Redundancy principle*: people learn better from graphics and narration than from graphics, narration, and printed text.
  - *Spatial and temporal contiguity principle*: people learn better when corresponding words and pictures are (1) presented rather near than far from each other on the page or screen, and are (2) presented simultaneously rather than successively.
- Principles for managing essential processing in multimedia learning.
  - *Segmenting principle*: people learn better when a multimedia message is presented in user-paced segments rather than as a continuous unit.
  - *Pretraining principle*: people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts.
  - *Modality principle*: people learn more deeply from pictures and spoken words than from pictures and printed words.
- Principles for fostering generative processing in multimedia learning.
  - *The multimedia principle*: people learn better from words and pictures than from words alone.
  - *Personalization, voice, and image principles*: (a) people learn better from multimedia presentations when words are in a conversational style rather than a formal style. (b) People learn more deeply when words in a multimedia message are spoken by a friendly human voice rather than by a machine voice. (c) People do not necessarily learn more deeply from a multimedia presentation when the speaker's image is on the screen rather than not on the screen.

Any principle is based on 4 to more than 20 experiments confirming the hypothesis behind the respective principle with remarkable effect sizes. In almost all experiments, recall and transfer are used as dependent variables and prior knowledge as an intermediate variable. As the process of multimedia learning is based on the integration of texts, pictures, and prior knowledge, the latter plays a decisive role. Novice learners require more instructional support to integrate the new information into a coherent mental model than learners with higher levels of prior knowledge. An instructional picture explaining the interplay of different variables may be necessary for novice learners to understand the material. At the same time, it may even be detrimental for more experienced learners as it may interfere with existing knowledge structures, or at least be redundant, inducing unnecessary extraneous cognitive load. This effect is referred to as "expertise reversal effect" (Kalyuga et al. 2003) or "individual differences principle" (Mayer 2009). Other variables that have been shown to mediate the effectiveness of multimedia learning are spatial ability, reading ability, and learning time.

Therefore, the principles on how to design multimedia instruction as summarized by Mayer (2009) should not be conceived as strong commandments. They rather summarize empirical evidence drawn from studies that rely on theories on the nature of human cognitive processing, which seek to explore the conditions under which these principles apply.

Critics of the research refer to the fact that the instructional material used in the majority of the experiments consists of rather short learning sequences, which reduces the external validity. Other questions address possible interactions of the independent variables with variables of the general learning situation, such as time-on-task or self-regulated vs. system-regulated learning. There is more research warranted using longer instructional sequences and different conditions of the learning situation. Although there is empirical evidence for the personalization, voice, and image principles as principles for fostering generative processing in multimedia learning, the theoretical explanation of the results seems as yet insufficient.

Mayer's theory of multimedia learning is called a *cognitive* theory, but there is no doubt that motivational and emotional or affective variables do influence multimedia learning. There have only been the first steps in research to study the influence and interactions of those variables. A theoretical model that integrates cognitive, emotional and motivational variables has been introduced on interactivity (Domagk et al. 2010). It is related to multimedia learning, as interactive features such as feedback, guidance, and learner control are also discussed in the context of multimedia learning, especially in the design of animations and simulations.

Cross-References

- ► Animated Pedagogical Agents
- ► Audiovisual Learning
- ► Cognitive Load Theory
- ► Computer-Based Learning
- ► Interactivity in Multimedia Learning
- ► Learning with Instructional Animations
- ► Mental Models
- ► Modality Effect
- ► Multimodal Learning Through Media
- ► Pictorial Representations and Learning
- ► Redundancy and Learning
- ► Role of Prior Knowledge
- ► Split Attention Effect
- ► Working Memory

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Multimedia Modality

► Effects of Multimedia Redundancy in History Learning

Multimethod Research on Learning

► Mixed Methods Research on Learning

Multimodal Learning

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Synonyms

Bimodal learning; Multisensory learning

Definition

Multimodal learning refers to an embodied learning situation which engages multiple sensory systems and action systems of the learner. This type of learning is traditionally emphasized for children with learning challenges, and can include a variety of visual inputs in addition to text. Some examples include pictures, art, film, video, and graphic organizers. Auditory inputs can include text-to-speech synthesizers, various forms of singing and musical instruments, rhyming, and spoken language games. One salient example is the use of the alphabet song to learn the alphabet. Tactile inputs are often manipulatives such as the use of an abacus for math learning, sculpting materials such as clay, paint, and paper for representing objects and ideas, and puzzles for fact learning such as learning the states and their capitals. Finally, kinesthetic engagement includes all forms of motor behavior and gesture such as jumping rope to memorize songs and hop scotch to practice school lessons. A recent trend is the change from fairly passive computer games such as Sudoku, Tetris, and

Solitaire to much more active types of game activity such as the sports and fitness games for the Wii Nitendo (2010). Another trend with great promise is the creative integration of the physical engagement of traditional hands-on board games with miniaturization technology and methodology from wireless sensor networks, as in siftables (Sifteo 2010).

An interactive multimedia environment is ideally suited for multimodal learning. For example, incorporating text and visual images of the vocabulary to be learned along with the actual definitions and sound of the vocabulary facilitates learning and improves memory for the target vocabulary and grammar. At the same time, the learner is actively engaged by listening to the words, pronouncing the words, and if literate, reading and writing the words. In one typical application (Massaro 2006; Animated Speech Corporation 2010), a computer-animated agent guides the students to (1) observe the words being spoken by a realistic talking interlocutor, (2) experience the word as spoken as well as written, (3) see visual images of referents of the words, (4) click on or point to the referent or its spelling, (5) hear themselves say the word, followed by a correct pronunciation, (6) spell the word by typing, and (7) observe and respond to the word used in context. Although half of the exercises involve multiple choice testing, there is evidence that this experience boosts performance on later tests. The other half of the tests involve either spoken or written generation of the students' answers, which facilitates learning (Metcalfe and Kornell 2007). The test exercises can be viewed as learning exercises because testing has been demonstrated to increase learning and retention.

In a recent experimental test, children, whose native language was Spanish, were tutored and tested on English words they did not know. The research utilized a multiple baseline design to insure that any learning was due to the application itself rather than from outside of the lesson environment. The children learned the words when they were tutored but not words that were simply tested. This result replicates the previous studies carried out on hard of hearing and autistic children with Baldi as the animated conversational tutor. In other experiments, we have also observed that Baldi's unique characteristics allow a novel approach to training speech production to both children with hearing loss (Massaro 2004) and adults learning a new language.

Theoretical Background

Perhaps the most germane background for Multimodal Learning is Montessori's Principles of Educational Practice (Stoll-Lillard 2005). Montessori's Principle 1 claims that motor behavior and cognition are closely intertwined and that physical movement can enhance thinking and learning. At first glance, this principle seems the antithesis of direct computer-aided instruction with an animated tutor. However, we have learned that our nervous systems appear to be wired in a way that observations of actions activate neural mechanisms involved with the actual performance of those actions. The so-called mirror neurons involved in performing an action are activated when that action is observed. One possibility, therefore, would be to implement lessons on Nintendo's Wii to allow the child to have larger physical movements. Another would be to have animated movies as well as pictures for learning.

Montessori's Principle 2 states that choice and perceived control promote children's concentration and contentment in the learning process. As is currently exists, direct instruction does not appear to allow much choice. On the other hand, the child can be given a library of lessons and she can choose the lesson to study. A precocious child might even be able to create a lesson of her choosing.

Principle 3 assumes that personal interest enhances learning in a context where interests build on prior knowledge and the children's own questions. For example, a deaf French child used the Lesson Creator to document her travel and holiday pictures in a set of English vocabulary lessons. Thus, learning a new language was facilitated by involving her direct experience and interests with a normally tedious task.

Principle 4 indicates that extrinsic rewards negatively impact long-term motivation and learning. Rewards and feedback can be controlled exactly in computer-assisted learning. Directed feedback can allow errorless learning without focusing on rewarding the child for correct answers and punishing the child for incorrect answers.

According to Principle 5, collaborative (child–child) arrangements are conducive to learning. Although most automated instruction is one-on-one and precludes collaborative learning, this principle can be instantiated in several different ways. First, the animated agent can be a child who works along with the child. Second, children can work together on a lesson or on creating lessons, and can even distribute the required learning and thereby achieve the benefits of the Jigsaw Classroom.

Principle 6 assumes that learning situated in and connected to meaningful contexts is more effective than learning in abstracted contexts. Although most automated instruction can be considered relatively unsituated and not connected to a meaningful context, the Lesson Creator allows the immediate creation of lessons on subjects that are currently taught: Just-in-time learning. Thus, the child sees the value and appropriate context of the lesson when it is connected to her appropriate interest and cognitive level.

Principle 7 claims that sensitive and responsive (nurturing) teaching is associated with more optimal outcomes. Tutors can be created and programmed to be highly nurturing. For example, the difficulty of the lessons can be controlled to meet the child's preferred difficulty level, and errorless feedback can be provided.

Principle 8 assumes that order in the environment promotes and establishes mental order and is beneficial to the child. Direct instruction is highly orderly in its functioning, which adheres to this principle.

Another relevant background source is the empirical and theoretical literature on multimedia learning (Mayer 2005). This research, for example, gives principles for the ideal placement of illustrations in science texts. It is a challenge to have both illustrations and written text appropriately placed. Usually this requires that the text is placed near the referent. Gestalt principles of organization could be used to insure that the text and the appropriate aspect of the illustration are perceived as near one another. Spoken language during the lesson is not easily localized because of our perceptual limits in perceiving small differences in the localization of sound. In this case, the appropriate part of the illustration can be highlighted while it is being discussed. More generally, it is important to make it easy for the learner to hold pictorial and verbal representations in working memory at the same time. Finally, when illustrating a sequence of events, successive or causal links in the sequence should be presented near one another.

A theory that serves important background for Multimodal Learning is the Fuzzy Logical Model of Perception (FLMP) According to this model, multiple sensory influences are combined before categorization and perceptual experience. In face-to-face speech perception, for example, the FLMP assumes that the visible and audible speech signals are integrated. Before integration, however, each source is evaluated (independently of the other source) to determine how much that source supports various alternatives. The integration process combines these support values to determine how much their combination supports the various alternatives. The perceptual outcome for the perceiver will be a function of the relative degree of support among the competing alternatives. Across a range of studies comparing specific mathematical predictions, the FLMP has been more successful than other competitor models in accounting for the experimental data (Massaro 1998).

The FLMP has proven to be a universal principle of pattern recognition. In multisensory texture perception, for example, there appears to be no fixed sensory dominance by vision or haptics, and the bimodal presentation yields higher accuracy than either of the unimodal conditions. Preschool as well as school children integrate auditory and visual speech to produce a multimodal benefit of having two sources of information relative to just one. In addition, both hard of hearing children and autistic children appear to integrate information from the face and the voice. These results from typically developing children as well as deaf and hard of hearing and autistic children indicate that multisensory environments should be ideal for speech and language learning.

Important Scientific Research and Open Questions

There are, of course, many remaining research and theoretical questions to be addressed in future research. For example, one might question why perceivers integrate several sources of information when just one of them might be sufficient. Most of us do reasonably well in communicating over the telephone, for example. Part of the answer might be grounded in our ontogeny. Integration might be so natural for adults even when information from just one sense would be sufficient because, during development, there was much less information from each sense and therefore integration was all the more critical for accurate performance.

A natural question concerns the neural mechanism underlying the integration algorithm specified in the FLMP. An important set of observations from single cell recordings in the cat's brain could be interpreted in terms of integration of the form specified by the FLMP. A single hissing sound or a light spot can activate neurons in the superior colliculus. A much more vigorous response is produced, however, when both signals are simultaneously presented from the same location. The FLMP is mathematically equivalent to Bayes' theorem, which is an optimal method for combining two sources of evidence to test among hypotheses. The brain can implement an analogous computation so that the response of a neuron is proportional to the posterior probability that a target is present in its receptive fields, given its sensory input. Therefore, the target-present posterior probability computed from the impulses from the auditory and visual neurons is higher given sensory inputs of two modalities than it is given input of only one modality, analogous to the synergistic outcome of the FLMP. This type of research informs questions about the neural underpinings of Multimodal Learning.

Multimodal Learning situations are often implemented in virtual rather than real worlds. It is feasible that limiting the students' experience to the two-dimensional world of computer monitors would constrain learning relative to a live teacher. The success of two-dimensional media such as the television and the Internet, however, is a real-world experimental proof of the sufficiency of two dimensions for learning. To date, tutoring on two-dimensional surfaces appears to be as effective as live tutoring, although additional research is still required on this question. However, with the exploding popularity of three-dimensional (3D) movies such as *Up* and *Avatar*, and the increasing availability of 3D projection systems, TVs, and computer monitors, learners will more often find themselves in more realistic simulated 3D worlds.

Cross-References

► Cross-Modal Learning
► Multimedia Learning

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Multimodal Learning Through Media

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Synonyms

Audiovisual learning; Collaborative learning; Cone of experience; Cone of learning; Learning pyramid; Multimedia learning

Definition

Multimodal Learning refers to the using of multisensory approaches to learning, combined with higher-order experiences such as interactivity. The differential learning outcomes are of significant interest due to potentially large impact on retention and actuation.

Theoretical Background

"A picture is worth a thousand words." This common saying has been attributed to Confucius, Napoleon, and others, but its true author is unknown. Emergent neuroscience and visualization research now reveals glimpses of the science behind the saying. Visuals matter, and so does interactivity. Our brains are wired to process visual input very differently from text, audio, and sound. There is also increasing recognition about how much we learn via social mechanisms. Recent technological advances through functional Magnetic Resonance Imaging (fMRI) scans confirm a dual coding system through which visuals and text/auditory inputs are processed in separate channels, presenting the potential for simultaneous augmentation of learning. Students using well-designed combinations of visuals and text, accompanied by interactivity, learn more than students who only use text. Also, interactivity matters more for acquisition of higher-order skills, rather than basic skills.

Important Scientific Research and Open Questions

Historical Perspective: Cone of Experience

Edgar Dale (1954), an early researcher in the field of visual learning and the father of the Cone of Experience is credited for the original linkage between instructional theory and communications media. Dale's original model is explicitly described as a visual aid about audiovisual materials. Dale's cone of experience is essentially a "visual metaphor" depicting types of learning, from the concrete to the abstract. Dale did not intend to place value on one modality over another. The shape of the cone is not related to retention, but rather to the degree of abstraction (Dale 1946/1954/1969). However, he does contend that, as one's experiences move toward the bottom of the cone, more of the senses are engaged (such as hearing, seeing, touching, smelling, and tasting).

How People Learn: The Cognitive Science

A 2001 publication from the US National Academy of Sciences, *How People Learn* (Bransford et al. 2000) outlines important principles upon which learning should be redesigned:

- Student preconceptions of curriculum must be engaged in the learning process: Learning is greatly enhanced when prior knowledge is made visible. It is at that point the learner has the opportunity to correct misconceptions, build on prior knowledge, and create schemas of understanding around a topic. Learning is optimized when new concepts build on prior knowledge.
- Expertise is developed through deep understanding. Students learn more when the concepts are personally meaningful to them. In order to deeply understand a topic, learners not only need to know relevant facts, theories, and applications, they must also make sense of the topic through organization of those ideas into a framework (schema) of understanding. This translates into a need for authentic learning: depth of concept, relevance to learner in the real world, and learner's use of the key ideas in a production.
- Learning is optimized when students develop metacognitive strategies. To be metacognitive is to be constantly "thinking about one's own thinking," in search of optimizing and deepening learning. Metacognitive learners approach problems by automatically trying to predict outcomes, explaining ideas to themselves, noting and learning from failures, and activating prior knowledge.

Multimedia Design: Principles

As a reminder, a set of principles related to multimedia and modality are listed below (from Richard Mayer, Roxanne Moreno, and other prominent researchers [Mayer 2001; Ginns 2005]).

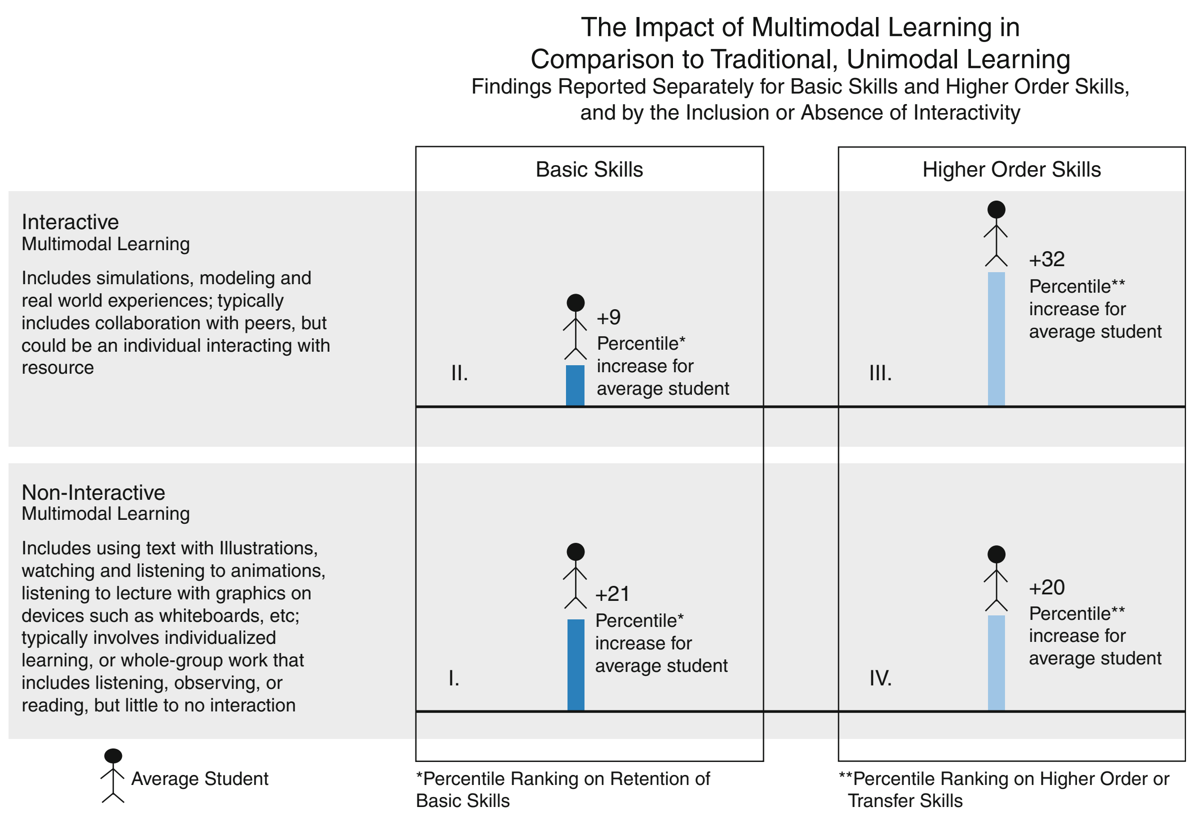
1. Multimedia Principle: Retention is improved through words and pictures rather than through words alone.
2. Spatial Contiguity Principle: Students learn better when corresponding words and pictures are presented near each other rather than far from each other on the page or screen.
3. Temporal Contiguity Principle: Students learn better when corresponding words and pictures are presented simultaneously rather than successively.
4. Coherence Principle: Students learn better when extraneous words, pictures, and sounds are excluded rather than included.
5. Modality Principle: Students learn better from animation and narration than from animation and on-screen text.
6. Redundancy Principle: Students learn better when information is not represented in more than one modality – redundancy interferes with learning.
7. Individual Differences Principle (a): Design effects are higher for low-knowledge learners than for high-knowledge learners.

8. Individual Differences Principle (b): Design effects are higher for high-spatial learners rather than for low-spatial learners.
9. Direct Manipulation Principle: As the complexity of the materials increase, the impact of direct manipulation of the learning materials (animation, pacing) on transfer also increases.

Multimodal Learning: Impact of Interactivity

The complexity of teaching and learning becomes increasingly apparent as the physiological, cognitive, social, and emotional aspects of learning become known. The most effective designs for learning adapt to include a variety of media, combinations of modalities, levels of interactivity, learner characteristics, and pedagogy based on a complex set of circumstances. In general, multimodal learning has been shown to be more effective than traditional, unimodal learning. Adding visuals to verbal (text and/or auditory) learning can result in significant gains in basic and higher-order learning. Figure 1 (Cisco Systems – Metiri Group 2008) below provides insights into when interactivity augments multimodal learning of moderately to complex topics, and when it is advantageous for students to work individually when learning or building automaticity with basic skills.

- Quadrants I and II: The average learner scores on basic skills assessments increase by 21 percentiles when engaged in noninteractive, multimodal learning (includes using text with visuals, text with audio, watching and listening to animations or lectures that effectively use visuals, etc.) in comparison to traditional, single-mode learning. When that situation shifts from non-interactive to interactive, multimedia learning (such as engagement in simulations, modeling, and real-world experiences – most often in collaborative teams or groups), results are not quite as high, with average gains at nine percentiles. While not statistically significant, these results are still positive.



Multimodal Learning Through Media. Fig. 1 Comparison between unimodal and multimodal learning

- Quadrants III and IV: *When the average learner is engaged in higher-order thinking using multimedia in interactive situations, on average, their percentage ranking on higher-order or transfer skills increases by 32 percentile points over what that learner would have accomplished with traditional learning*. When the context shifts from interactive to noninteractive multimodal learning, the result is somewhat diminished, but is still significant at 20 percentile points over traditional means.

Open Questions

- Impact of the agent of interactivity: Physical person versus virtual person versus machine
- Impact of group size
- Impact of learner's age
- Multiplicity of types of social interactions
- Scaffolding required to prepare learners to the effective use of multimedia
- Learning designs necessary to minimize cognitive overload throughout learning

Cross-References

► Adaptation to Learning Styles
► Adaptive Blended Learning Environments
► Collaborative Learning Supported by Digital Media
► Learning with Instructional Animations
► Multimodal Learning

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Multiple

► Cue Summation and Learning

Multiple Cognitive Abilities

► Multiple Intelligences and Learning Styles

Multiple Intelligences and Learning Styles

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Synonyms

Frames of mind; Multiple cognitive abilities

Definition

The theory of Multiple Intelligences (MI) was introduced by Howard Gardner (1983) in his book *Frames of Mind*. Its main characteristic is the assumption that individuals differ not only in a single intelligence (g or general intelligence) but rather in a set of relatively autonomous intelligences. Intelligence is defined as a biopsychological potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture (Gardner 1999). In contrast to MI which is associated with individual differences in cognitive abilities, the term ► Learning Styles refers to individual differences in the habits, preferences, or orientation toward learning and studying. Research into learning styles has developed independently of Gardner's theory, but the MI profiles were sometimes misinterpreted as learning styles.

Theoretical Background

Gardner emphasized that the theoretical basis for the MI theory was the combination of empirical findings from a variety of disciplines, including psychology, neuroscience, anthropology, and cultural studies. Following this multidisciplinary approach, he set up a list of criteria that have to be met for a cognitive ability to be defined as one distinct intelligence:

1. The existence of a separate brain region supporting the relevant cognitive functions

2. A plausible evolutionary history
3. An identifiable set of core operations
4. Susceptibility to encoding in a symbol system
5. A distinct developmental history
6. Evidence from individuals with distinctive low (e.g., specific learning disabilities) or high (e.g., savants, prodigies, geniuses) intelligence
7. Support from experimental psychological tasks
8. Support from psychometric findings

In his original work, Gardner (1983) described the following seven intelligences and, in later publications, added some examples of geniuses in the respective intelligence which should illustrate the importance of each intelligence for life success.

1. Linguistic intelligence reflects the sensitivity to spoken and written language, the ability to flexibly manipulate language to express oneself, and the ability to learn new languages. A high linguistic intelligence could be found, for instance, in writers and public speakers. Thomas S. Elliot was given as example for a genius in this intelligence.
2. Spatial intelligence refers to the ability to envision and transform visual-spatial representations. High levels of spatial intelligence would occur in pilots, architects, engineers, and sculptors (e.g., Pablo Picasso).
3. Logical-mathematical intelligence represents the ability to reason deductively and think logically, to detect complex mathematical patterns and to work scientifically. This intelligence would be prominently pronounced in mathematicians, logicians, and scientists, such as Albert Einstein.
4. Musical intelligence consists of the ability to recognize, compose, or perform musical patterns (pitches and rhythms) and could be typically found in composers and performers (e.g., Igor Stravinsky).
5. Bodily kinesthetic intelligence is described as the potential of using the own body in problem solving or in creating products. Example professions are dancers (e.g., Martha Graham), actors, athletes, surgeons, and craftsmen.
6. Intrapersonal intelligence is the knowledge of and access to one's own feelings and desires and the ability to use this knowledge effectively in real life. Psychologists and psychotherapists such as Sigmund Freud would possess a high level of this intelligence.
7. Interpersonal intelligence was defined as the capacity needed for successful interaction with other individuals, i.e., the understanding of intentions, motivations, and needs of others, and the ability of working effectively with them. Physicians, teachers, politicians, salesman, and actors would require high interpersonal intelligence to be successful in their profession. The example genius in this intelligence was Mahatma Gandhi.

In 1999, Gardner apparently combined the latter two intelligences to one Personal intelligence and put forward two further intelligence candidates: Naturalistic intelligence, as the ability to process information related to distinguishing among natural and manmade objects and, Existential intelligence, as the ability to see oneself in relation to further reaches of the cosmos. The latest modification of the MI theory (Gardner 2004) was the proposal of two overarching intelligence profiles that describe the ways in which the autonomous intelligences interact: searchlight and laser. The first can be understood as a profile in which various intelligences are of comparably high strengths, whereas the latter characterizes individuals who demonstrate one or two powerful intelligences that overshadow the other intelligences.

Important Scientific Research and Open Questions

Since its introduction, the MI theory has attracted a great deal of attention in education as well as in the general public. This was, for instance, reflected in an increasing number of (commercial) workshops on how to adapt teaching to the implications of the MI theory. A plausible reason for the still great popularity of MI theory might lie in the simplicity of the theory suggesting that the human mind (and brain) can be divided into seven to nine separate intelligences and that there is a high probability that every individual is intellectually gifted in at least one of them. In addition, even though Gardner repeatedly highlighted that MI theory does not have direct educational implications, some recommendations have been put forward by him and others as to how the theory can be implemented in the classroom.

In the community of psychologists, in particular of intelligence researchers, the MI theory has been severely criticized on multiple grounds (e.g., Waterhouse 2006). First, it has been highlighted that the theory does not adequately consider evidence from well-established psychometric intelligence research and is not innovative. The assumption of relatively independent intelligence factors has already been elaborated in the first half of the twentieth century (e.g., Thurstone's primary mental abilities), and many of the proposed intelligences can also be found in other theories on intelligence structure (e.g., the hierarchical model of intelligence by Carroll). This holds particularly true for linguistic, spatial, logical-mathematical, and musical intelligence. The personal intelligence shows similarities to the concept of social intelligence by Thorndike and emotional intelligence by Salovey and Mayer, and the bodily kinesthetic intelligence may be related to practical intelligence proposed by Sternberg. Second, even after more than 25 years since its proposal, no psychometric tests have been developed to assess the MI. Gardner argued for the development of "intelligence-fair" tests that look directly at the intelligence without the linguistic or logical components that are required in traditional paper-and-pencil test. Spatial intelligence, for instance, could be assessed through the observation how individuals navigate in an unfamiliar terrain or how an individual can take apart and reassemble a mechanical machine. Despite the plausibility of this approach, no test has been proposed so far that meets all the essential diagnostic criteria of objectivity, reliability, and validity. Other researchers used self-report measures to assess MI, where individuals were asked about their interests, leisure activities, and self-concept. Given that the correspondence of self-reports with performance measures is typically rather low, and that self-reports should be applied *after* an ability construct can successfully be measured using performance tests, also this attempt can be put into question. Third, the theory itself has not been empirically validated. The argument by advocates of the MI theory that its generation was already based on empirical findings from various disciplines does not make an empirical validation dispensable. Although some of Gardner's claims are vague and do not reflect clear-cut hypotheses that can be falsified, some key assumptions of the theory have been scrutinized but could not be confirmed. Large-scale studies have, for instance, revealed considerable correlations between measures of the supposedly independent intelligences and strong associations with general intelligence (e.g., Visser et al. 2006). The introduction of the searchlight and laser intelligence profiles further complicates an empirical investigation as statistical interdependence could be justified to reflect the searchlight and statistical independence the laser intelligence profiles. As another example, Gardner's claim that each intelligence is supported by a separate neural structure also stands in contrast to current knowledge about brain organization. Finally, despite the great popularity of MI theory among educators, the educational implications are unclear, and it is debatable whether any recommendations can be derived that go beyond current knowledge in the educational sciences (cf. Klein 2003). The following suggestions to bring MI theory to classroom were offered by Gardner: using multiple points of entry, multiple representations, and analogies and metaphors. Multiple points of entry refers to teaching in a way which engages many or all of the intelligences. As an example, students could learn about the revolutionary war by studying battle maps, learn revolutionary war songs, read a novel about life during that period, or perform role plays. Some students may prefer one of the activities over others, and this might also be related to their intelligence profiles. But Gardner has not further explained the relationship between the multiple entry points and the multiple intelligences and has also not provided specific information on how both should be matched to improve learning. Similarly vague are the recommendations to use multiple representations (e.g., linguistic, pictorial, mathematical) of a curricular topic as well as analogies and metaphors (within and between intelligences) which should foster the interaction of different intelligences. Undoubtedly, multiple representations, analogies, and metaphors are valuable tools to acquire curricular topics, but the incremental insights that are gained by considering the MI theory are unclear.

Apart from these critical issues which also represent open questions for future research, the principal merit of MI theory can be seen in emphasizing that real-world success is not only a function of psychometric intelligence, but also of domain-specific knowledge and skills. This claim is in line with findings from expertise research showing only weak or moderate correlations between general intelligence and expert performance and that lower intelligence can be compensated by more knowledge in domain-specific performance.

Cross-References

- ▶ Abilities to Learn: Cognitive Abilities
- ▶ Emotional Intelligence and Learning
- ▶ Expertise
- ▶ Intelligence, Learning and Neural Plasticity
- ▶ Learning Style(s)

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Multiple Resource Theory

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Synonyms

Mental resources; Resource limitations

Definition

The Multiple Resource Theory asserts that people have a limited set of resources available for mental processes. These resources can be thought of as a pool of energy that is used for a variety of mental operations, from sensory-level processing to meaning-level processing. This shared pool of resources are allocated across different tasks, modalities, and processing. This theory explains how difficult single-tasks can run into processing difficulties and how dual-task performance is more likely to be hampered by performing similar tasks than dissimilar tasks. Multiple resource theory has been applied in psychology to areas such as dual-task performance as well as applied areas such as communication to understand how people make sense of television messages and in consumer research to understand how people process information about a product.

Theoretical Background

One of the most fundamental assumptions in cognitive psychology is that people's ability to process information is limited. This perspective believes that people are only able to evaluate a limited amount of information at a time, and exceeding that threshold results in "information overload." Supportive of the general assertion, some research demonstrated that providing too much information can reduce decision quality. An important issue underlying resource limitations is the underlying reasons for these limitations and mechanism behind it. Theory and research have focused primarily on how the attentional process selects some information to come into our consciousness at the expense of other information. Many theorists believe that overload is avoided through attention mechanisms that direct consciousness at some items and away from others.

A critical question underlying the notion of information limitation is the question of where are the possible resource limitations or bottlenecks in the process. Research has had difficulty identifying any consistent bottleneck as proposed by the early theorists, such as one ear or in terms of the number of "bits" of information. A tenable alternative to a fixed or static bottleneck is the notion of dynamic resource limitations. According to this approach, people perform multiple mental operations on incoming information with attentional limitations that regulate which operations can be performed. With this formulation some research began to examine the specific levels of information or pacing where people were overloaded, especially in a single channel perspective (Wickens 2002).

Important Scientific Research and Open Questions

The resource limitation paradigm has been tested in the area of consumer decision making. For example, research has examined whether the provision of additional information results in lower-quality decisions. The results of this research, however, have not been straightforward in identifying specific levels of information beyond which the processing degrades. As a result there has been some debate on not only the meaning of the results, but also the results themselves. Evidence seems to suggest that additional information might not be employed, and may even reduce some measures of decision quality, but does that necessarily indicate "overload."

As a result of these failures and others to identify a specific bottleneck at specific stages or processes, an even more dynamic attention mechanism was proposed – termed "Multiple Resource Theory" (Wickens 1980). According to this theory people have a pool of resources available to a variety of operations, from sensory-level processing to meaning-level processing. Wickens (2002) traces the origins of this theory to attentional models including Kahneman's. Multiple Resource Theory explains how dual-task performance is more likely to be hampered by performing similar tasks than dissimilar tasks (Wickens 1980). In later research Wickens and colleagues demonstrated support for the notion of a shared pool of common resources allocated across different tasks, modalities, and processing (Wickens 1980, 1984, 2002).

Research has applied the notion of multiple resource pools to processing television information, which typically consists of a stream of auditory and visual stimuli that need to be processed at both a sensory and semantic level (Lang 2000). Application of this paradigm has suggested the intentional use of secondary task measures, such as response times to cues, as an indicator of available resources (Basil 1994). Despite the logic of this approach, empirical insights provide a somewhat confusing picture of secondary tasks performance (Lang and Basil 1998). In generally though, the evidence from this line of research does support the notion of resource limitations that result from these dynamic processes, and that the bulk of these limitations appears to result from meaning-level processing (Lang 2000). A critical prediction of Multiple Resource Theory, the level of "redundancy" between the audio and visual information has emerged as a predictor of the information load on viewers. To the extent that audio and visual information "match up" the information task processing is easier and more resources appear to be available as is predicted by Multiple Resource Theory.

Multiple Resource Theory has other important applications. Possible applications of Multiple Resource Theory include a variety of human performance tasks, including driving while talking on a mobile telephone (Wickens 2002). If we can understand the availability and overlap of these resources to various tasks, we can predict overload and design interactive environments that are less likely to result in overload (Wickens 2002). MRT also has implications for consumer information processing. For example, to what extent can people make sense of nutrition labels? Understanding when people are overloaded by information, and how this can be avoided has important implications in the realm of consumer disclosure.

Despite general agreement on the concept of attention, there is still debate on what form that attention takes – a "spotlight" or general activation and whether attention determines "consciousness." Even with the continuing debate on the exact mechanism, it is important to realize that the fundamental assumption supported by Multiple Resource Theory is that information processing requires cognitive resources, which can overload to privilege some information at the expense of other information.

Cross-References

▶ Attention and Implicit Learning
▶ Audiovisual Learning
▶ Audio-Video Redundancy
▶ Capacity Limitations of Memory and Learning
▶ Cognitive Load Measurement
▶ Dual-Task Performance in Motor Learning
▶ Interactive Learning Environments
▶ Mental Effort

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M

Multiple-Cue Probability Learning

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Synonyms

Function learning; Lens model; Probabilistic categorization; Weather prediction task

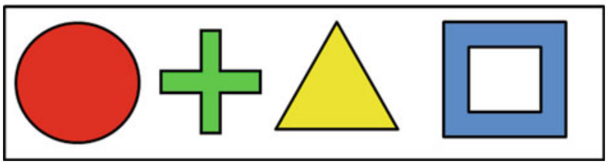
Definition

Multiple-Cue Probability Learning (MCPL) is an experimental paradigm concerned with how well people can learn imperfect relationships between cues and outcomes. In a typical MCPL task, participants are shown an array of cues each of which predicts a particular outcome with some probability; usually this probability is less than unity, mirroring the imperfect nature of cues in the natural environment. The cues are usually instantiated as simple perceptual stimuli, which can be either discretely (often binary) valued, such as color – a given cue might be a red or green, for instance – or stimuli can be comprised of continuously valued dimensions – such as bars of different lengths. The former case with discrete cues is typically referred to as *nonmetric* multiple-cue probability learning (NMCPL), and the latter case with continuous cues is termed *metric* multiple-cue probability learning. Outcomes or responses are typically discrete (e.g., press a button when shown cue A, but do not press the button when shown cue B) or categorical (press the button for category X or Y, depending on the cue configuration); however, some variants of the MCPL task use continuous outcomes. Depending on the types of cues and outcomes, MCPL is often very similar to other concept-learning domains; a classification of the most popular domains is shown in Fig. 1. The key distinguishing element of MCPL is the fact that the corrective feedback that follows each response is probabilistic rather than deterministic; those cells are shaded in Fig. 1.

As an illustration of MCPL, consider the weather prediction task shown in Fig. 2 (the task is called a weather prediction task because the outcomes are usually given arbitrary names such as RAIN and SHINE). The stimuli are comprised of four cues. Each cue can either be present or absent on each trial, and for the present example, only one shape may be presented on each trial. Each cue is represented by a different shape that can be used to predict an outcome, in this case with probabilities equal to 0.45, 0.55, 0.80, and 0.40 for outcome X, for the four cues, respectively. (Note that in this example, there are only two possible outcomes. The opposite outcome, call it Y, is predicted with one minus the probability of outcome X; in this example,

		Feedback			
		Deterministic		Probabilistic	
	Outcomes →	Discrete	Continuous	Discrete	Continuous
Cues	Discrete	Categorization	Multiple Cue Judgment	NMCPL Multiple-Cue Learning Weather Prediction Task	Multiple Cue Judgment
	Continuous	Categorization	Function Learning	Metric MCPL	MCPL

Multiple-Cue Probability Learning. Fig. 1 Classification of concept-learning paradigms based on cues, outcomes, and feedback



Probability of outcome X	
Circle	.45
Plus	.55
Triangle	.80
Square	.40

Multiple-Cue Probability Learning. Fig. 2 Example of an MCPL task

P(Y) is 0.55, 0.45, 0.20, and 0.60 for the four cues, respectively.) The cues vary in how well they predict the outcomes, if a participant responded with X every time she were shown a triangle, she would be correct 80% of the time.

Unlike other learning paradigms, MCPL does not primarily focus on learning strategies but on how closely people's behavior matches the relative information available in the cues. For example, of the four cues in Fig. 2, the triangle is a more valid predictor than the other three symbols; higher levels of accuracy can be attained by using only this cue to guide decision making and ignoring the other less valid cues. The core concept of *validity* refers to how well a cue predicts a given outcome; cues with high validity are good predictors of an outcome whereas cues with low validity give little or no information about what the outcome might be. In MCPL, primary importance is placed on how well people *utilize* cues of different validities; that is, do people base their responses and decisions on cues with greater validity? And how well does observed cue utilization compare with optimal cue utilization?

The optimal strategy for the example in Fig. 2 is to always respond X when a triangle is present and respond Y when a triangle is absent; although this response strategy, known as "maximizing" cannot avoid the inevitable error arising from probabilistic feedback, it can at least maximize accuracy. However, people typically deviate from this optimal strategy and instead match their response proportions to the underlying probabilities. That is, when shown a triangle, people tend to respond X only 80% of the time (reducing accuracy from a possible 80% to 64%); when shown a plus sign, they respond with X only 55% of the time; and so on. Probability matching is commonly observed in decision-making and categorization tasks. One way to examine probability matching is by computing a measure of achievement, such as the correlation between response proportions and the underlying feedback probabilities.

Theoretical Background

MCPL originated as a method to apply Egon Brunswik's ideas about probabilistic functionalism, which were initially developed to study visual perception, to learning and behavior. Probabilistic functionalism is the idea that the external environment and internal perceptions of that environment are variable, and that to function successfully in a variable environment, an organism must learn to utilize only reliable and valid cues (Brunswik 1943). Probabilistic functionalism thus emphasizes the imperfect nature of the environment (and organisms). Foremost among Brunswik's concerns were that psychological laboratory experiments should use stimuli and feedback which represent the probabilistic nature of the environment and that the external environment should be given as much prominence in psychological theory as the organism in that environment. The former concern has clear reverberations in modern concerns about ecological validity; the latter concern predated rational approaches to cognition (e.g., Anderson 1990), but was perhaps better advocated by Brunswik's contemporary, James Gibson, culminating in ecological psychology and dynamical systems approaches to perception, cognition, and action.

Important Scientific Research and Open Questions

MCPL is related to several other domains, and many tasks which are currently popular (such as function learning) have direct precursors in the MCPL literature. However, the use of MCPL as a tool for studying learning declined substantially in the late 1970s, concurrent with a shift in cognitive psychology toward emphasizing computational modeling of the processes and representations underlying learning behavior (cf. Estes 1976). MCPL's preoccupation with simple measures of achievement ("how well can people learn?") was abandoned in favor of measures of strategy and prediction ("what and how do people learn?").

However, several important studies have thus sought to differentiate computational models using NMCPL.

In NMCPL, two sources of cue information have been studied extensively: cue validity and cue salience. Salience refers to some intrinsic property of the cue which attracts attention regardless of how useful or valid that particular cue may be. The research in NMCPL has indicated that validity and salience trade-off in predictable ways. Table 1 provides a summary of the main findings. People are good at learning which cues are valid for a given task and will utilize those cues accordingly. If all of the cues have the same validity then people will utilize cues with higher saliency. Increasing either a cue's validity or its saliency will enhance its utilization (to the detriment of other cues). Irrelevant cues also impact performance – adding an irrelevant cue decreases utilization of a valid cue, but the effect depends on the salience of the irrelevant cue – people must "notice" the irrelevant cue in order to utilize it and it takes a highly salient cue to attract attention to what is irrelevant (see Kruschke and Johansen 1999). People are also more adept at utilizing a single cue than using cues comprised of combinations or configurations of single cues.

The weather prediction task illustrated in Fig. 2 has been used extensively in studies of neurocognition, primarily to examine dissociations between declarative and procedural memory. The task putatively does not involve declarative memory because recalling previous trials should not help the learner avoid errors due to probabilistic feedback. Instead, the weather prediction task is presumed to rely on some implicit knowledge of the underlying probabilities associated with each cue combination. (In typical applications of the weather prediction task, on any given trial, any combination of present and absent cues may be shown to an observer; hence, cues occur not only in isolation but also in combination with other cues.) In support of this hypothesis, patients with amnesia were as successful as controls in learning the task (Knowlton et al. 1996). Because the weather prediction task (and MCPL generally) is concerned primarily with the aggregate cue utilization following learning, it is not clear to what extent differential strategy use plays a role in these studies. For instance, responses generated by always using a single cue can often result in similar performance to using a conjunction of cues (Gluck et al. 2002). Consequently, participants might follow a number of different strategies to arrive at the same level of aggregate performance making it difficult to infer what different levels of performance actually mean. Hence, it is difficult to assess the degree to which MCPL might rely on memory or implicit knowledge; however, recent analyses have aimed to determine the underlying strategy used in MCPL tasks and not just the level of accuracy.

Multiple-Cue Probability Learning. Table 1 Summary of important MCPL findings

Increased validity leads to increased utilization
Decreased validity leads to decreased utilization
Increased salience leads to increased utilization
Decreased salience leads to decreased utilization
Validity and salience interact
Increased utilization of one cue decreases utilization for other cues
Salient but irrelevant cues decrease utilization of valid cues
Single cues are easier to utilize than configurations of cues

Cross-References

- ► Behaviorism and Behaviorist Learning Theories
- ► Cognitive Tasks and Learning
- ► Complex Learning
- ► Cue Summation and Learning
- ► Design of Learning Environments
- ► Human Feature Learning
- ► Neuropsychology of Learning

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Multiple-Documents Literacy

► Knowledge Acquisition: Constructing Meaning from Multiple Information Sources

Multiple-Texts Comprehension

► Knowledge Acquisition: Constructing Meaning from Multiple Information Sources

Multiplicative Reasoning

► Multiplicative Thinking and Learning

Multiplicative Structures

► Multiplicative Thinking and Learning

Multiplicative Thinking

► Multiplicative Thinking and Learning

Multiplicative Thinking and Learning

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Synonyms

Multiplicative reasoning; Multiplicative structures; Multiplicative thinking

Definition

Multiplication (and division) is an arithmetic operator used on numbers while thinking is a cognitive process involving the mind of learners reacting to incoming information. Multiplicative thinking represents the learner's mental adaptive processing of multiplication concepts by using different methods and approaches in various mathematical problem contexts. Considering the level of complexity inherent in the nature of multiplication, one requires a more complex approach when thinking about numbers and operations. Multiplicative thinkers are those who have understood the concept of multiplication and are able to apply the concepts and solve problems relationally.

Theoretical Background

Multiplicative thinking has gained more recognition and interest in recent years, following the early work of Vergnaud in 1983. The growth of multiplicative thinking is critical for a learner's conceptualizing or articulating of his or her world. However, studies reveal that many conceptual stumbling blocks that learners encounter in the elementary and even middle school curriculum are related to multiplicative thinking. The inability to bridge the gap from additive to multiplicative thinking is a significant reason causing this variation which impedes a meaningful understanding of the mathematics curriculum. Determining what experiences might be important to foster this understanding requires a thorough analysis of the schema of children's thinking in the area of multiplication. Some of the questions we need to ponder are: What do we know about multiplicative thinking/structure? What are the ways learners build on such structures? What cognitive operations underlie such structures? Three major perspectives on multiplicative thinking have argued on the analysis of multiplicative construct and the cognitive structures necessary to understand it.

The first perspective on building dimensional relationships between quantities in multiplicative situations was pioneered by Vergnaud in 1983. A diagrammatic representation was developed to illustrate the structure of multiplicative problems (see Fig. 1). This structure called "isomorphism of measures" consists of the relation between two measure spaces (or units) M1 and M2, comprising two different quantities. Examples of this relation are distance and time, items purchased and their cost, etc.

Given that a, b, and c are provided and that x is missing, two kinds of operators, namely, the scalar operator and functional operator are proposed. The scalar operator transposes the operator linking a to c in M1 to the other measure space M2, and then applies it to b to get x (see Fig. 2). It is called scalar because it is a ratio of two magnitudes of the same unit and has no dimension.

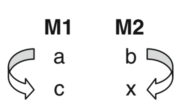
The functional operator transposes the operator linking a to b on the upper line to the lower line and applies it to c to get x (see Fig. 3). It is called functional because it represents the coefficient α of the linear function f(x) = αx from M1 to M2. Its dimension comprises the quotient of two other dimensions (e.g., price of pizza, miles per hour).

The analyses on this dimensional relationship (proportionality) are based on fundamental multiplicative structures applied in relational problem contexts and represented at different levels of abstraction from simple to more complex situations. However, it does not discuss explicitly the learner's voice and ways of talking. Beyond these formal structures, one should ask, how learners construct their own multiplicative thinking based on their schema?

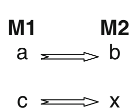
The second perspective involves the measure of units where learners build on prior knowledge of multiplication and model the situations based on their schema. Here, the development of multiplicative thinking requires that learners construct and coordinate three aspects of multiplicative situations (groups of equal size, number of groups, and the total quantity), "in such a way that one of the composite units is distributed over the elements of the other composite unit" (Steffe 1994, p. 19). This scheme involves taking a set as a countable unit (the number of groups) while maintaining the unit nature of its element (groups of equal size). There is a significant difference between this pre-multiplication iteration from the conventional 4 × 3 of four groups and three units in it (3 + 3 + 3 + 3) as the basis for repeated addition. Iterate simply means the repetition (distribution over another) of the unit, and in this iteration scheme, the 4 indicates four iteration of an iterable unit 3 (3, 6, 9, 12). Iterating is a form of distributing one quantity across another (3, 3 + 3, 6 + 3, 9 + 3).

M1	M2
a	b
c	x

Multiplicative Thinking and Learning. Fig. 1 Representation of isomorphism of measures



Multiplicative Thinking and Learning. Fig. 2 Scalar operators



Multiplicative Thinking and Learning. Fig. 3 Functional operators

These iteration schemes can develop or progress to a more abstract level of cognizing multiplicative thinking. The following table (Table 1) illustrates this level of competency (through a problem context) from a pre-multiplying scheme to Vergnaud's (1983) isomorphism of measures to illustrate the iterative structure of multiplicative thinking.

Question: Mariam needs exactly 3 cups of water to make 4 small cups of coffee. How many cups of coffee can she make with 12 cups of water?

Situation 1: Pre-multiplying Scheme

A buildup procedure that uses an additive strategy which is based on establishing a relationship within a ratio (3:4) and extending it to the second ratio by addition.

Situation 2: Iterative Multiplication Scheme

A simultaneous coordination of the invariant iteration of multiples 3 and 4 and distributing one of the composite units over the elements of the other composite unit.

Situation 3: Scalar Functional Operator

A formal structure that involves finding a multiplication scalar (unit factor 12/3 = 4) and multiplying it with 4 that gives 16.

Learners curtailed this iteration process by using known multiplication facts to help determine the total

Multiplicative Thinking and Learning. Table 1 Three development levels of a multiplicative thinking situation

Pre-multiplying scheme (Repeated addition)	Iterative multiplication scheme	Scalar functional operator
3 C water makes 4 C coffee	3 C water makes 4 C coffee	x 4 (3 C water → 4 C coffee; 12 C water → ?) x 4
3 C water makes 4 C coffee	6 C water makes 8 C coffee	
3 C water makes 4 C coffee	9 C water makes 12 C coffee	
3 C water makes 4 C coffee	12 C water makes 16 C coffee	
12 C water makes 16 C coffee		
Repeated addition of 3:4	Iteration of 3:4	Multiply with a scalar operator of 4
Symbolically,	Symbolically,	Symbolically,
12:16 = (3:4) + (3:4) + (3:4) + (3:4) + (3:4)	12:16 = 4(3:4)	$4 \times 12/3 = 16$

C Cup

number of iterations. This curtailment requires learners to sufficiently abstract the iteration action so that one can reflect on it and anticipate that the result of several iterations can be captured by a known multiplication fact. This will reflect the learner's ability to move from the fundamental iteration schemes to a more abstract level of understanding in multiplicative thinking. This level of competency represents Vergnaud's (1988) representations of isomorphism of measures to illustrate the structure of multiplicative problems.

The third perspective is based on multiplicative actions independent of addition ideas using the analysis of actions and images (e.g., partitioning, splitting). This paper-folding (partitioning) learning activity involves a fractional part (1/2, 1/3, or 1/4) to determine the number of equal parts made by a series of the actions (of folds) and the resulting sequence of folds. This serves as a basis for multiplicative thinking. This folding activity can also generate learner thinking on exponential functions as they progress (see Table 2). Example

- If you fold a piece of paper in half four times, how many equal parts will you create? (have the students predict, then fold)

  One fold makes 2 parts, two folds make 4 parts, three folds make 8 parts, four folds make 16 parts.

  Symbolically, halving a paper generates an exponential function of 2^1, 2^2, 2^3, in determining the number of equal parts.
- If you folded a piece of paper and created 32 equal parts. How could you have folded the paper?
- Jenny folded a piece of paper into three equal parts, then eight equal parts. Jason folded his piece of paper into six equal parts. If he wants to make exactly as many parts as Jenny has, how many parts should he fold his paper into next?

These folding action activities embody many-for-one (Dienes 1967) multiplicative structure, in that each fold creates many parts and operates on the parts created by previous folds. It is theorized that having learners making connections between the number of folds and the number of parts created, and reflecting upon these folding tasks could facilitate the development of multiplicative thinking (in terms of anticipatory structures) which can progress to exponential thinking. In fact, this analysis seems to point to actions on actions (kinesthetic movement) as opposed to iteration of number scheme which points to units of units.

Important Scientific Research and Open Questions

The iterating scheme does suggest that children begin using counting strategies, progress to pre-multiplying scheme (strategies based on repeated addition), and finally, use features of scalar (or functional) multiplication operators to solve problems. Although observations have been made on learners' multiplicative thinking development, the thought processes involved in such thinking are not clear. It is well established in the literature (e.g., Jacob and Willis 2001) that some learners never reach the stage of effectively using

Multiplicative Thinking and Learning. Table 2 Fold in equal parts of two, three, and four

Fold in two equal parts (Half)	Fold in three equal parts (One third)	Fold in four equal parts (Quarter)
One fold makes 2 parts (2×2^0)	One fold makes 3 parts (3×2^0)	One fold makes 4 parts (4×2^0)
Two folds make 4 parts (2×2^1)	Two folds make 6 parts (3×2^1)	Two folds make 8 parts (4×2^1)
Three folds make 8 parts (2×2^2)	Three folds make 12 parts (3×2^2)	Three folds make 16 parts (4×2^2)
Four folds make 16 parts (2×2^3)	Four folds make 24 parts (3×2^3)	Four folds make 32 parts (4×2^3)
Symbolically n folds = $2 \times 2^{n-1}$	n folds = $3 \times 2^{n-1}$	n folds = $4 \times 2^{n-1}$

multiplicative thinking as there is an overreliance on the pre-multiplying scheme based solely on repeated addition. How, then, do learners bridge the gap between the three approaches to multiplicative thinking? Research (e.g., Susan and Erin 2006; Confrey 1994) has indicated the emergence of multiplicative thinking in learners' solutions through paper-folding tasks (splitting and partitions). Is the splitting/partitioning learning activities the answer to bridging the gap?

In general, the relative difficulty of multiplication word problems is affected by the type of multiplier, and in these schemes (iteration of number scheme and partition/splitting), it is based on whole numbers. Will learners be able to apply these schemes to a decimal multiplier (larger or smaller than 1) or fraction? These perspectives also do not cater for many influential variables in a problem situation like text, structure, context, and syntax.

One of the goals of research is to identify important mathematical knowledge of learners based on their thinking processes and schemas, and start developing them early. Identifying and understanding such thinking processes will allow multiplicative domains to become widely accessible to all learners from early childhood through early adulthood. Taken together, the three perspectives do identify the important processes and give the reader a variety of choices about how to conduct research in the multiplicative conceptual field. However, do these perspectives provide an adequate framework for assisting learning and teaching of multiplication in schools? These three perspectives are rich in ideas; however, their implication for classroom practices is less clear. In developing adept multiplicative thinkers, one needs to assess learners' current level of thinking (where they are), the context (or dimensions) of the important multiplicative processes (where they need to go), and the use of the different perspectives or approaches needed (how to get there).

Cross-References

► Learning Activity
► Learning Numerical Symbols
► Learning Strategies
► Mathematical Learning
► Mental Arithmetic
► Schema(s)

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Multi-representational Learning Environments

▶ Metacognition and Hypermedia Learning: How Do They Relate?

Multi-robot

▶ Multi-robot Concurrent Learning

Multi-robot Concurrent Learning

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Synonyms

Cooperation; Machine learning; Multi-robot; Reinforcement learning

Definition

Multi-robot Concurrent Learning means a team of *autonomous* robots (or agents) learning to achieve a desired collective task. Learning is achieved by interaction with other robots and the environment. Learning can be done in a *distributed* way where each robot learns on its own, in a *centralized* way where learning is realized in a central computing system that communicates with the robots, or a combination of distributed and centralized learning. Current research activities focus on: (1) learning algorithms based on the robot's interactions where sensing and actuation are typically corrupted with noise, (2) concurrent learning where the behavior of a robot is affected by what it has learned and thereby affecting other robots' learning and behaviors (stability issues have to be addressed), and (3) robots having different capabilities and learning may need to discover these capabilities and to take advantage of them.

Theoretical Background

Multi-robot System Introduction

Cooperative multi-robot system is a wide research topic spanning many applications including multi-robot cooperative material transportation, distributed sensing, exploration and mapping, team formation and marching, robot soccer, etc. The cooperative multi-robot system is more than just a simple extension of the single-robot system. It not only increases the performance and robustness of the system by parallel operation, but it is also able to accomplish the tasks impossible for a single-robot system through "cooperation." The term "cooperation" is widely used in robotics literature. Cao et al. (1997) states that "Given some task specified by a designer, a multiple-robot system displays cooperative behavior if, due to some underlying mechanism (i.e., the "mechanism of cooperation"), there is an increase in the total utility of the system."

Compared to a single-robot system, the cooperative multi-robot system is distinguished by the following aspects:

- Multi-robot systems can accomplish some inherently complex tasks that cannot be accomplished by single-robot systems, e.g., two robots carrying a load that is impossible for one robot to carry.
- Multi-robot systems can enhance the performance by working cooperatively to achieve performance better than combined performance of individual robots.
- Multi-robot systems are more robust than single-robot systems because failures of robots, in general, do not critically affect the ability of the robot team to accomplish the collective task.
- As compared with an expensive and multifunctional robot, the cost of a team of simple robots may be cheaper.

Multi-robot System Classification

Generally, multi-robot systems can be categorized by their control architectures (centralized or distributed), robot differentiation (homogeneous or heterogeneous), and cooperation level (low to high).

Centralized and Distributed

In centralized control, a commander (a leader robot or a host PC) gives commands to every robot, whereas in decentralized control each robot makes decision by itself and works with other robots without the need for a central controller. An important advantage of distributed control is the higher level of robustness, since the task is not solely dependent on the central controller. But the resources available (e.g., computing power) of individual robots are in general much less than that of a central controller. The best system combines both centralized and distributed control to achieve an optimum collective execution of the task.

Homogenous and Heterogeneous

If all robots are identical, the team is homogeneous, otherwise it is heterogeneous. In a heterogeneous robot group, individual robots usually have different physical configurations and capabilities. For example, a robot team can have several subgroups, one group can serve as the "brain," another group as actuators, etc.

Action Level Cooperative or Task Level Cooperative

Multi-robot systems can be classified as task level cooperative or action level cooperative, depending on the level of cooperation (Tangamchit et al. 2002). In task level cooperation, the mission is broken down into simpler tasks; each robot chooses different tasks (roles) and behaves differently, according to the task allocated to it. Action level cooperation does not differentiate between the behaviors of the robots. It is usually accomplished by enabling the robots to work in parallel. The term "cooperation" in action level cooperation only refers to the fact that a robot will not impede others, e.g., collision. For instance, in a robot soccer team, task level cooperation allows the robots take on different tasks (behaviors), such as defending, passing, and shooting. On the contrary, if the cooperation is at the action level, the mission is not divided and all the robots try to achieve the same goal: get the ball and then kick it toward the goal. Task level cooperation, in general, has superior performance compared to action level cooperation. Depending on the application, a hybrid combination of task and action levels of cooperation may also be needed (e.g., many robots carrying and transporting a common payload).

Multi-robot System Control Methodology

In robotics research, four basic policies are usually used to control the robot: reactive, deliberative, hybrid, and behavior-based control. They can be summarized as follows (Mataric 2001):

- Reactive control: do not think much, just act depending on sensor inputs.
- Deliberative control: think first, and then act.
- Hybrid control: think and act independently at the same time.
- Behavior-based control: think the way to act.

The characteristics of the mission and the environment, and the capabilities of robots determine the control policy that is suitable for a given mission. Reactive, deliberative, and hybrid controls are usually used in single-robot systems and are able to achieve action level cooperation in multi-robot systems. Behavior-based control is more complex, but it can achieve task level cooperation in multi-robot systems. Behavior-based control is therefore a popular control methodology that is applied to cooperative multi-robot systems.

Multi-robot Concurrent Learning

There is extensive literature on single-robot learning. However, the basic learning algorithms for single robot, such as concept learning, decision-tree learning, artificial neural networks, Bayesian method, computational learning, instance-based learning, and genetic algorithms, are seldom used for multi-robot learning. Two basic assumptions, Markov decision process and stationary environment, which are usually valid in the single-robot domain, are inapplicable in multi-robot domains due to the interactions among the concurrently learning robots (Kaelbling et al. 1996). One class of solutions to address this problem is to estimate the influence of other robots and consider the process as semi-Markovian and pseudo-stationary for an individual learning robot. Another class of solutions is to coordinate or schedule the distributed learning processes to reduce interference. However, the coordination and scheduling of the learning processes have to be deliberatively designed and usually require explicit communications among the robots.

For multi-robot systems, reinforcement learning is extensively studied. This is due to the fact that behavior-based control is very popular in multi-robot systems, and reinforcement learning (RL) is suitable for behavior-based control because it focuses on learning directly from the feedback of the environment. Another explanation is that other machine learning algorithms, such as Genetic Algorithms, have heavy computational burden and may not be practical for robots used in multi-robot systems; therefore they are not extensively used.

Reinforcement Learning for Multi-robot Concurrent Learning

Reinforcement learning is a simple but powerful learning algorithm that is model free, does not require strict supervision, and can be optimal subject to user defined criteria (Sutton and Barto 1998). In addition, reinforcement learning provides a natural fit for the behavior-based control which requires the robot to "select" optimal actions under any given state (Mataric 2001). For example, a robot can use the reinforcement learning algorithm to learn the elementary behavior "avoid obstacles," such that when it is "near to an obstacle" ("high level" state), it will carry out the ("high level") action "make a detour along the boundary of the obstacle."

In last three decades, reinforcement learning has been extensively studied for multi-robot concurrent learning of cooperative behaviors. However, to apply reinforcement learning to behavior-based control, the designers usually need to discretize the continuous input state space and output action space. The problem associated with discretization is that if the discretization is too coarse, some states may be hidden and the optimal control policy cannot be found; if the discretization is too fine, the states cannot be generalized and the huge state/action space will adversely impact the learning speed. In addition, if the states and actions are discretized and finite, the behaviors will also be discrete and finite because the robot can only perform one action corresponding to a single behavior at any one time. This contradicts the human reasoning that the optimal solution to accomplish a task may comprise the concurrent execution of several elementary behaviors. Furthermore, switching among discrete behaviors usually results in unsmooth control, which is undesirable in most scenarios. With respect to this problem, several methods have been proposed to enable reinforcement learning in continuous space without discretization. The function approximation approach applies a generalizing function approximator to estimate the state-action value instead of using discrete lookup tables. Also, reinforcement learning can be used to derive optimal feedback control laws for linear/nonlinear systems. However, these approaches usually assume that the environment model is known and may incur heavy computational burden if the training data set is large. Another class of solutions is to integrate reinforcement learning with Fuzzy Inference Systems (FIS) by allowing the reinforcement learning module to learn/tune the fuzzy rules for the FIS. The FIS can then retrieve continuous and infinite states and perform the corresponding actions. These deliberatively designed approaches can tune the FIS to achieve satisfying performance; however, the control architecture and learning algorithm are usually complex and the applications are mostly for low level control involving simple tasks and missions, e.g., approaching targets with obstacle avoidance.

Important Scientific Research and Open Questions

Multi-robot concurrent learning usually applies reinforcement learning algorithms and aims to obtain the desired behavior-based control system. The reinforcement learning module has to retrieve discrete input states and perform discrete actions. A challenging work is to design a totally continuous and infinite space learning algorithm, and enable the robot to perform state/action discretization through learning. This is an important research issue to be studied.

Another problem associated with the learning controller is that the behavior-based control system is usually specific to one type of cooperation task. If other type of cooperation task is selected the specific behavior-based control system has to be redesigned accordingly. If the control system is inappropriately designed and does not fit the requirements of the task, reinforcement learning may not work optimally. Therefore, the performance of the system can be greatly improved if the behavior-based control system is generic and effective for all types of control problems. This is another important research issue to be studied.

Last but not the least, in distributed learning controllers, the interference among the concurrent learning robots may cause the distributed learning controller to generate unsatisfying results. Another future research topic of importance is to examine how communications (both direct/explicit or indirect) can be exploited to achieve better concurrent learning.

Cross-References

- ► Collaborative Learning
- ► Collective Learning
- ► Group Learning
- ► Robot Learning

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Multisensory Integration

► Intersensory Facilitation

Multisensory Learning

► Multimodal Learning

Multi-sensory Neurons

A multi-sensory neuron exhibits an altered response (e.g., in terms of spike rate or activation threshold) by concurrent stimulation from more than one modality. Different types of multi-sensory neurons have been identified in different brain areas in mammals and other animals.

Multistrategy Learning

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Synonyms

Dynamic selection; Induction and abduction; Inferential strategies; Learning methods; Workflow design

Definition

Multistrategy learning (MSL) is concerned with developing learning methods and systems that integrate different inferential and/or representational strategies in solving a given learning task. In general, a learning task is defined as a composition of three components: the type of knowledge to be learned, the input information available to the learner, and the learner's prior (or background) knowledge. As for *integration of different strategies*, different people attribute a different meaning to this term. Some are concerned with different *inferential* strategies, such as *induction* and *abduction*. Others explore combinations of several *different learning methods* for the same goal and a particular inferential strategy. Moreover, the learning methods may be accompanied auxiliary computational processes (e.g., pre-preprocessing). Others are concerned mainly with *dynamic selection of learning methods* for the same learning goal. A more general problem involves decomposing a learning goal into subgoals and selecting suitable (learning) operators for each subgoal. The last alternative can be referred to as *workflow design* and can involve planners.

Theoretical Background

Due to complementary nature of different learning strategies, multistrategy learning approaches have a potential for a wider range of applications than monostrategy systems. The field of *multistrategy learning* goes back to the 1980s where various authors began to integrate various techniques or methods, although the term got into use later. In the period 1991–2000, a series of five workshops was organized under this name in different countries. The first one was organized by R. Michalski and G. Tecuci in 1991. After 2000 the activities in this area continued usually under different names, but clear links can be established. This issue is addressed further on in this entry.

As has been mentioned in definition given above, MSL methods or systems integrate different inferential and/or representational strategies. It was mentioned that different people attribute a different meaning to this term. In the following various different interpretations are covered in more detail. The aim is to provide an up-to-date view, taking into account the new developments in the last decade.

Combining Different Types of Inferential Strategies

In this setting, we may require that the inferential methods should be radically different methods, such as, for instance, *induction generalization, abductive derivation or deduction* discussed by Michalski (1994). Knowledge transformations are referred to in this setting as *transmutations.* Abstractions and specializations (concretions) change the level of detail. The aim of this research is to organize different inferential strategies into one coherent whole specifying the conditions determining which strategy should be triggered when (i.e., under what conditions).

This setting is really a challenging one, as it requires that the architecture of an intelligent agent be defined in some detail, including the relationship between mechanisms responsible for knowledge acquisition and transformation with recourse to different inferential strategies (incl. induction) that the agent may have recourse to. Although in the last decades, various proposals have been made concerning the general architecture "*intelligent systems*" that includes also learning, no consensus has been established. Note that the architecture involves a so-called control task, that involves the issue of determining which mechanism to employ when. This is sometimes referred to as *meta-level control.* The meta-level control is often defined with recourse to symbolic methods (e.g., logic), as in Michalski (1994).

As defining the architecture is a kind-of all encompassing task, and hence rather difficult, many people preferred to consider more restricted sub-areas related to this general setting.

So, for instance, one may try to determine how to design systems that exploit both *induction* and *abduction.* This has drawn interest of a part of the community and led to organization of specialized workshops on this topic (e.g., Flach and Kakas 2000).

The interdependence between the level of detail and learning has recently been addressed in the area referred to as Knowledge Discovery from Databases (KDD). Detailed information is stored in a Data Warehouse and the level of detail can be changed on demand using *drill-up*/*drill-down* operations.

Others have included various types of mechanisms of arriving at knowledge, including perception, communication, learning, and deployment of learned models, but the activity is restricted to a particular domain to make this tractable. One good example is robotic soccer. The experience gained in this rather specific task may be of use in other types of domains.

Another interesting line of research aims at extending symbolic reasoning and learning to incorporate probabilistic information, giving rise to reasoning and learning in probabilistic logics (de Raedt 2008).

There is no doubt that this area will continue to be investigated in future. So far, the progress has not been as fast as one would wish, as the investment to develop such systems is high and the return, when trying to solve real problems, is not immediate. This is the main reason why researchers have devoted their attention to some of the problems discussed below, which lead to more immediate returns.

Combining Different Learning Methods Within the Same Learning Strategy for the Same Goal

One sub-area of MSL is concerned with *model combination* for the same learning goal (e.g., classifying examples). We note that models that are being combined involve the same learning strategy (e.g., classification learning). As this sub-area is easier to tackle than the more general goal described above and has led to practical benefits, it has witnessed a great expansion in the last two decades. There are two basic approaches to model combination. The first one exploits variability in the given data and combines multiple copies of a single learning algorithm applied to different subsets of data. The most famous examples of this type include *bagging* and *boosting.* The second one exploits variability among learning algorithms. This approach includes, for instance, *stacking* and *cascade generalization.* As both the inference mechanism and learning goals are fixed, the aim is to improve a given measure of success (e.g., classification error).

Machine Learning Method Accompanied by (or Preceded by) Auxiliary Computational Processes

In this setting we require that some learning method, when complemented by some auxiliary computational method (or several such methods) has some advantages over the original learning method. The auxiliary computational method is usually included for a specific aim (e.g., to overcome some shortcoming of the learning method).

Many contributions in the area of MSL in the past would fall into this sub-type. They were not limited to the task of classification, but rather covered most areas of machine learning, including theory revision, causal modeling, combination of symbolic and sub-symbolic methods, improving rule-based classification using genetic algorithms, using clustering prior to regression, etc. Many of the topics in this list appear as articles in literature on this topic (e.g., Michalski and Tecuci 1994).

Some authors tried simply to show that their work simply includes more than one method, overcoming thus some shortcomings of the predecessor systems. This is the case of using clustering prior to regression. We note that normally the component types in each proposal were fixed by the designer. For instance, in the work on improvement of rule-based classification using genetic algorithms, the work included a *rule-based classification learning* supplemented by an auxiliary method, *genetic algorithms*, whose aim was to identify the apparently best rule set.

We note that the distinction between multistrategy and monostrategy learning approaches may be arguable. For instance, we recollect that a decision tree classifier incorporates a pruning technique. A Naive Bayes classifier may incorporate a built-in discretization algorithm. Many learning systems have evolved to be quite complex and incorporate various techniques to achieve a given goal. Whenever a combination of techniques has been established and has proved itself useful, it is normally regarded simply as a whole, albeit more sophisticated than its predecessor. So to regard these as *multistrategy learning systems* nowadays would be questionable.

Before ending this section, we need to mention one special kind of sequence of operations, referred to as Knowledge Discovery from Databases (KDD). It presupposes an existence of some data source (e.g., Data Warehouse). The classical sequence of operations that is then applied involves data selection, data preparation (e.g., selection of features), data mining, and post-processing. Data mining is normally seen as a process that selects a suitable machine learning method for training and/or deployment. Again, we note that specific communities have been established that have turned this sub-area into their main object of research.

Dynamic Selection of Machine Learning Method that Exploits Meta-level Information

As the number of machine learning algorithms grows, the problem arises which one is to be selected for a given task. The problem arises, as no single algorithm is the best one for all problems. Some researchers have thus explored the possibility of using meta-level information (metadata) to guide the process of selection, making the selection dynamic. Meta-level information (metadata) includes, in the first place, information concerning problems dealt with in the past by applying different machine learning algorithms (e.g., classifiers) and their corresponding performance. Besides, it includes also some characteristics of the new problem. The aim is to exploit all this in order to predict (recommend) the best type of method (classifier) for the new problem (Brazdil et al. 2009).

Dynamic Multistage Processing that Exploits Meta-level Information and Planning

This topic can be seen as a combination of the previous two lines. It involves dynamic selection of algorithms or methods, but the objective is not to select a single machine learning method, but rather (partially ordered) sequences of processing steps, which is usually referred to as *workflow*. So, the objective can be formulated as *workflow design*. This can be done either manually or automatically. Manual workflow design is usually done with the help of visualization techniques. Many data mining systems, such as SPSS Clementine, Weka, RapidMiner or KNIME (among others) include the possibility of composing workflows by dragging in icons representing the individual operations. Current approaches that are being investigated use planners to compose workflows. Various techniques are used to make this process feasible and/or faster. These include usage of ontologies of operations, meta-level information characterizing individual operations, which in turn are used as heuristics that can be used to guide the search. These issues are the object of study in various specialized workshops (e.g., PlanLearn 2010).

Important Scientific Research and Open Questions

The area of combining different types of inferential strategies, that was originally described by (Michalski and Tecuci 1994) in the early days of MSL continues to be an important research question. As has been mentioned in the last decades various proposals have been made concerning the general architecture "*intelligent systems*" that includes also learning, but no consensus has been established. Note that the architecture involves the issue of determining which mechanism to employ when. The costs and benefits of differently employing such mechanisms (deciding what to do when) need to be carefully weighted at each step. These may involve determining what one wants to do, which may require certain knowledge resources. Then one needs to decide how the knowledge is to be obtained. This may be done using deductive inference, communication with other agents, or learning. Learning, if not defined exogenously, involves defining a learning goal, gathering new information or data required for learning, activating suitable pieces of background knowledge and initiating and controlling the learning process. This area is sometimes referred to as *meta-level control*. This process may be dynamic and involves planning certain cognitive actions. Although in the last decades, various proposals have been put forward and progress made in specific sub-areas, in our view this area will continue to be a challenge to the community.

Cross-References

- ► Abductive Learning
- ► Discrimination vs. Generalization
- ► Learning Algorithms
- ► Metalearning

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PlanLearn (2010) 3rd planning to learn workshop associated with ECAI-2010, Lisbon, Portugal. http://www.ifi.uzh.ch/ddis/planlearn10.html

Multivariate Regression

► Learning via Linear Operators

Music and Education

► Music and Learning

Music and Human Development

► Music and Learning

Music and Language Learning

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Synonyms

Musical expression; Musical interpretation; Musical nuance

Definition

► Musical expression is the performer's microtonal and/or microrhythmic variations around any notational fixed point.

Music cognition is the demonstration of perceptual awareness of musically organized patterns.

M

Language and music are ubiquitous in all human cultures that we know about. It has been argued that musical abilities and speech abilities develop in similar ways (Campbell and Heller 1980). The infant eventually learns to organize acoustic speech information into meaningful sounds. The young child develops an ability to learn the language of its parents. By the age of 5 or 6, the child has begun to master the intricacies of its culture's speech. This does not mean that abstract concepts and constructs are generally learned by age 6, but rather that the full range of *expression* in speech is normally learned by this age. The normal 6-year-old can tell when a parent is not happy with them by the manner in which the parent speaks. Before the age of 10, the child has already learned that *how* something is said may be more important than *what* is said. The pre-teenaged child has mastered a very complex set of language rules (Heller and Campbell 1982).

Theoretical Background

The underlying theory here presented is that music is learned in a similar manner that speech is learned. The young child's brain is destined to learn its *mother tongue* in speech and probably also in music. The human brain is designed to organize acoustic information into patterns. At some point early in life, these patterns become recognizable speech or other acoustic patterns (like music). The word *music* here is used to denote some organized set of acoustic patterns that is meaningful to some group of humans.

Researchers in language and brain functions have developed models of auditory processing that have provided new insights into musical learning (Patel 2008). With these models as guides, music researchers may be in a position to provide better answers for two basic questions that have important practical as well as theoretical implications. The first question is simply "Why study music;" the second is "How is music related to other categories of human experience?"

Music provides "a shared social/cultural contract" (Campbell and Heller 1981) that gives context for decoding the acoustic signal. *Music* (as defined here) is not meant to be something that is notated in a written code that can be learned. Musical notation is very much like written language. It is a system organized to encode something about *music* (the acoustic phenomenon), and language notation is used for a similar purpose, i.e., to encode something about *speech*. The word *encode* is used because music and speech are not *communicated* in the sense of a one to one literal transmission from performer (speaker) to listener. (There is no isomorphism here.) The word communication is not used because that word implies that there is a direct acoustic link of the stream of music or speech from the performer or speaker to the listener. This direct link conveys very little about the speaker or performer's intent unless both performer and listener belong to the same speech or musical culture. In this view, the performer *encodes* the message and the listener *decodes* the message, whether music or speech (Fiske and Heller 2010). If the listener is not part of the same musical culture as the performer, little, if anything, is decoded. Much like language, if a speaker is speaking a language, the listener does not speak, very little information is provided to the listener. Of course, there may be some global attributes of speech (loudness, gruffness, high or low pitch) that might convey certain meaning from speaker to listener, but, in general, unless the speaker and listener are part of the same general language culture, not much decoding can take place in the listener. This view holds as well for music.

In the development of language, there is a *learning window* that opens at birth (some say even before birth) and closes somewhere between the ages of 6 and 10. This same window may also operate for music learning (Heller and Campbell 1982). Since neurons in the brain become organized into patterns for speech use, they may also be used for a second language or for music. According to this theory, the learning window is accompanied by a *practice window* for language, but not necessarily for music. If such a practice window *for music* is made available to the very young child, then it would become possible for such a child to have the opportunity to learn the important expressive qualities necessary for musicality. In this case, the young child is able to learn the acoustic patterning rules of music. Both the learning window and practice window must overlap for mastery of language *and* music skills.

Important Research and Open Questions

Many researchers in cognitive psychology support the notion of a strong music and language connection. For example, musical syntax and linguistic syntax are compared. By and large, such connections are made based on notated variables like pitch, rhythm, and timbre. However, these studies do not generally consider the very important non-notated expressive nuance variables of music performance (Lerdahl and Jackendorff 1983; Patel 2008).

Most normal children have the opportunity to practice their language skills from birth onwards. Adults (usually parents) constantly teach their children how to speak from the earliest moments of life. This activity does not usually take place for learning *music* at such a young age. However, there are numerous examples of 3- and 4-year-old children learning to perform musically. These children have had a practice window that opened very early in their lives. Many ascribe a God given talent to these children. A more appropriate conclusion is that they have been lucky to have had the *opportunity to practice* their musical skills along with their language skills early in life.

Cross-References

- ▶ Enculturation and Learning
- ▶ Human Cognition and Learning
- ▶ Infant Language Learning
- ▶ Language Acquisition and Development
- ▶ Linguistic Factors of Learning
- ▶ Music and Learning
- ▶ Speech Perception and Learning

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Music and Learning

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Synonyms

Music and education; Music and human development; Music education

Definition

Music and learning may be interpreted in two ways. It may mean the learning of music or the role music plays in learning experiences. Whether they are a dichotomy or a continuum depend on the value music holds in the setting and how the musical experience is set up.

Theoretical Background

Evidence suggests that music was present in all ancient societies, including China, Egypt, Greece, and India. Music in ancient societies was inclusive of poetry and moral cultivation and was integrated with dance and other art forms. The learning of music was a key component in the human growth experience, at least based on philosophers such as Confucius (551–479 B.C.) and Plato (428–347 B.C.). However, music has become highly specialized and compartmentalized through the last two millennia. Today, while the key status of music learning has been taken over by other subjects, such as language and science, musicians have become highly specialized, leaving poetry, moral cultivation, dance, and the likes to other experts. Furthermore, the field of music has been broken down into many subfields, such as composition, musicology, ethnomusicology, performance, music theory, music education, conducting, and so forth. Even within performance, it is common to specialize in piano, violin, *erhu*, *kayagum*, percussion, or just about any instrument with a specialist at the local institution. While many music subfields constitute a foundation of training musicians, it is rare to see musical experts crossing over to another subfield. The learning of music itself seems to be highly specialized in contemporary societies.

Music learning is naturally connected to hearing abilities. The Native Americans often speak of the heartbeats of the mother and self, the first sounds humans hear as the fetus develops inside the mother's womb. The heartbeat, symbolized by a drumbeat in the Native American tradition, is the medium of connection among humans and the entire web of life. Be it fast or slow, it becomes a basic pattern for the vast majority of music–a regular and steady beat pattern. As the auditory abilities continue to develop after birth, humans learn about various sonic patterns, rhythmic, melodic, or in combination. Humans are able to discriminate among these patterns. These patterns are recognized, learned, understood, interpreted, and used in making music, using tools called instruments and the voice. Throughout the lifespan, especially during the first decade (Gordon 2003), humans collect a huge reservoir of musical patterns, from which they absorb, select, recall, produce, reproduce, and enjoy through various musical activities.

Music is one of the few human activities that could involve multiple modes simultaneously, aural, visual (e.g., looking at musical notation), kinesthetic (e.g., finger movement when playing a musical instrument), and touching (e.g., feeling of pressure on finger tips when playing the piano, the violin, or the hand-drum). It may occupy multiple domains simultaneously, cognitive, affective, and psychomotor. The cognitive faculty needs to be in full force when creating music, in composition, improvisation, musical analysis, or musical memorization while performing. The affective domain is stimulated during music processing, including music listening. The psychomotor function is activated whenever muscular motion is in place, such as playing an instrument or singing (considering the vocal folds are tiny muscles). Furthermore, social learning takes place as musical styles are being developed in a musician. The influence of culture is indisputable. Given the multiple facets of musical activities, music offers a unique potential to facilitate development in multiple modes and domains, and in social learning.

Besides formal and systematic music learning that takes place in school settings, much music learning takes place by way of enculturation, acculturation, and many forms of informal learning, including self-taught. Regardless of the means of music learning, various levels of accomplishments could be expected at different age levels. These levels of accomplishments could vary greatly depending on the environment and the type of musical stimulations available.

Based on neurological evidence, early and ongoing musical exposure affects the organization of the musical brain (Hodges 2000). This effect seems to be true to most other types of early exposures, such as language, mathematics, and chess. While there are many studies that indicate significant and positive correlations between music learning and performance in academic subjects such as language and mathematics, a causal effect has not been determined thus far. It is uncertain whether students with higher academic achievement are drawn to music learning or music learning has led to higher academic achievement. Regardless, it is clear that music learning is associated with higher academic achievement.

There has been some work in examining the effects of music on learning when music is played in the background. Some of this research has examined the effect of playing classical music for infants on their relaxation level. Other work has focused on the effects of playing classical music in the background on individuals' spatial reasoning skills. This work led to the blossoming of the *Mozart Effect*, a branch of research that focused exclusively on the effects of listening to Mozart's music on spatial temporal reasoning (Music Educators National Conference 2000). The results of this research seem to be inconsistent (Demorest and Morrison 2000). As a result, some researchers are skeptical about advocating for music instruction as a component of the education of all students on this insecure foundation.

A stronger argument for music studies might be gained by way of an understanding of music as a distinctive form of human intelligence. Howard Gardner's (1983, 2006) Theory of Multiple Intelligences clearly shows that music is a unique form of intelligence involving sound and that music is the earliest form of intelligence to emerge in an individual. No educational scheme should deprive an individual from developing any one of the forms of intelligence. Just like language, mathematics, and other forms of intelligences, music should be part of all educational structures. To allow individuals to grow as complete persons, all forms of intelligences, including music, must be developed.

In summary, music has shown to be a unique form of intelligence. Music learning should aim at developing this unique form of intelligence and making complete the human growth process. Evidence suggests that the effect of music on other types of learning is at best associational, speculative, and peripheral.

Important Scientific Research and Open Questions

Given the multifaceted nature of music and learning, research in this area is directly linked to music studies in cognitive psychology, developmental psychology, social psychology, educational psychology, and philosophy. Furthermore, there is an aesthetic dimension of music based on various cultural values. Considering the scientific aspects of music learning, a major driving force is the call for measurement, assessment, and evaluation. Measurement in music learning offers relatively objective information, such as a music test score. Assessment in music learning helps instructors to trace changes in the learning experience. Evaluation in music learning incorporates all available information to help make decisions in policy and future actions. These practices show accountabilities in the music teaching and learning experience. They may offer helpful information for the learner, the teacher, the parents, or anyone who cares about the learner's experience. There is so much scientific research done in music teaching and learning. Good places to begin looking at these studies can be found in the *Handbook of Research on Music Teaching and Learning* (edited by Richard Colwell 1992) and *The New Handbook of Research on Music Teaching and Learning* (coedited by Richard Colwell and Carol Richardson 2002).

Building on the idea that music and learning could mean the learning of music or the role of music in learning, the authors have developed the following model (see Fig. 1).

The model illustrates the interaction of how students, teachers, and curriculum (the design and plan for implementation of music making) affect both the learning of music and music in learning within the educational setting. None of these areas should be considered static. Rather, they should be viewed as complementary pieces of a complex puzzle. The act of music making in the *Learning of Music* side of the figure could be viewed as comprising all of the intersecting areas (students, teachers, and curriculum), with the focus being learning. The act of music making in the *Music in Learning* side of the figure could be viewed as comprising all of the intersecting areas (students, teachers, and curriculum), with the focus being music as one of a number of areas in general learning. Music making in the education setting is therefore influenced by beliefs about what each of these areas mean (students, teachers, and curriculum). Once researchers develop an understanding of what music and learning mean in their specific setting, and how each of the areas – students, teachers, and curriculum – affect what they are interested in regarding music learning or the role

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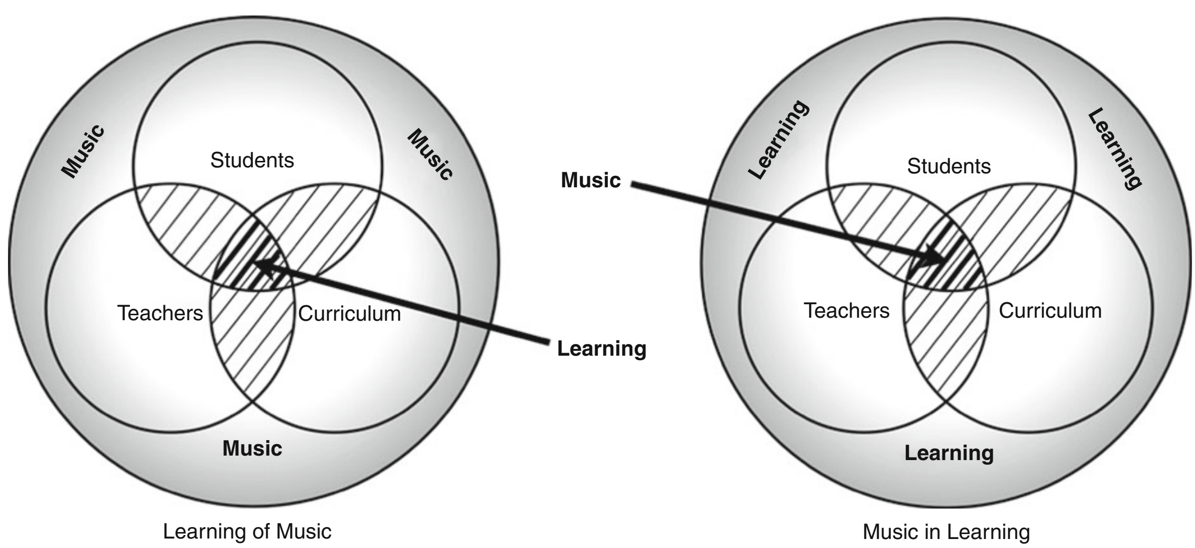

Music and Learning. Fig. 1 Model of music and learning that music plays in learning, they will then be able to more effectively develop research questions.

Current open questions in music and learning concern the uniqueness of music and other areas, music learning across cultures and time periods, and impact of informal music learning practices:

- What strategies can researchers use to determine a causal relationship between music learning and other types of learning?
- How is learning in music different from learning in other areas of formal education?
- How is learning in music different from other areas of learning in the arts, such as painting, sculpture, theatre, and dance? What areas of learning in music are similar to learning in the arts?
- What mechanisms for music learning are similar across a variety of cultures, and across time?
- Much of the studies in music learning, cognition, and development were done with Western art music and in Western cultures. What difference would it make if the research methodology of existing studies were modified to use music outside of the Western canon, and the data be collected in non-Western cultural contexts?
- What can music learning in formal education learn from informal music learning practices?

Hopefully, more studies along these lines will guide music and learning to a more prosperous path.

Cross-References

▶ Cognitive Psychology of Music Learning
▶ Composition Learning in Music Education
▶ Developmental Psychology of Music
▶ Instrumental Learning in Music Education
▶ International Perspectives in Music Instruction and Learning
▶ Multicultural Issues in Music Instruction and Learning
▶ Music and Language Learning
▶ Music Instructional Methods
▶ Research Methods in Music Instruction and Learning
▶ Social Psychology of Music Instruction and Learning
▶ Technology in Music Instruction and Learning

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Music Creation

▶ Composition Learning in Music Education

Music Education

▶ Music and Learning

Music Education Methods

▶ Music Instructional Methods

Music Instructional Approaches

▶ Music Instructional Methods

Music Instructional Methods

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Synonyms

Music education methods; Music instructional approaches; Music methodologies; Music pedagogies

Definition

Music instructional methods are pedagogies and approaches used in teaching music, based on theories of teaching and learning that have been developed through research. Each particular method has its own identifiable philosophy and unique instructional process. In addition, some methods utilize specialized materials or instruments.

Theoretical Background

Music instructional methods are framed by a plurality of theories of learning and instruction from the fields of education and music education. Theories of learning provide foundational knowledge of how students acquire knowledge, skills, and values. Theories of instruction result from research examining the relationship of (a) the perceived needs of learners, (b) the instructional processes of the teacher, (c) the learning processes of the students, and (d) the learning outcomes. Modern theories of learning and instruction are framed by the ideas of Johann Heinrich Pestalozzi (1746–1827), who believed that education should be "so sequenced and structured that each stage could grow naturally out of the preceding and into the succeeding stage" (Choksy et al. 2001, p. 5). These theories are also framed by the work of John Dewey (1902), who presented a holistic, pragmatic view of students and curricula, and emphasized that students should develop their capabilities through interaction with curricula that are relevant to their lived experiences. Contemporary theories that are particularly relevant to music instruction include those of constructivism, stage development, reinforcement, learning style, and instruction (Campbell and Scott-Kassner 2010). Table 1 provides more information and representative examples of each of these types of theories.

Important Scientific Research and Open Questions

The multiplicity of extant music instructional methods belies a consensus among music education practitioners and scholars as to the importance of methodology as a framework for music teaching and learning. At the same time, it illuminates a lack of consensus as to a best or most effective teaching method for specific age groups of students or types of learning environments. Some music educators are unwavering supporters of a single method, exemplifying the view that method should drive instruction. Others choose a method or combination of methods that best fit their personalities and preferences, endorsing the premise that method should be instructor-driven. Still others consider (a) their own personalities and preferences, (b) the needs and backgrounds of their students, and (c) the learning environment at hand, and combine elements from many methods to create a personal method that is both student- and instructor-driven. Music methods are developed from the desire to improve music education in some way. The open question remains as to whether one method is truly more effective than another, or whether effectiveness fluctuates due to differences among students, teachers, and learning situations.

Traditional Music Instructional Methods

Traditional methods of music instruction utilized in many countries include the Dalcroze, Kodály, Orff-Schulwerk, and Suzuki approaches. Of these, the Suzuki approach is used solely for instrumental music instruction. It is based on the belief that musical talent is not innate, but can be developed by any child. The Dalcroze, Kodály, and Orff-Schulwerk approaches are used in ► general music education, and share the contrary philosophy that each student possesses innate musicality. In addition, they support the view that music is essential to a well-rounded education, and place high value on active music making, including some form of movement. All four approaches begin music instruction aurally, rather than through introduction of musical notation. The following paragraphs provide more information about the outstanding features of each approach.

- Émile Jaques-Dalcroze (1865–1050), a Swiss musician, was a professor of harmony, ► solfège, and composition at the Geneva Conservatory in the 1860s. The *Dalcroze* approach was developed early in the twentieth century in response to what he perceived to be a general deficit among students in rhythm, pitch, and intonation accuracy. The approach consists of three components: (a) eurhythmics: concepts of rhythm, structure, and musical expression taught through movement, resulting in the development of an inner muscular

Music Instructional Methods. Table 1 Theories that inform music teaching and learning

Type of theory	Theorist(s)	Brief description
Constructivism	Jerome Bruner	• Learners develop understanding and make meaning of the world through their own experiences and through reflection on those experiences
Stage Development	Jean Piaget	• Learning occurs through four age-related stages of cognitive development: sensorimotor (birth-2 years), preoperational (2–7 years), concrete operations (7–11 years), and formal operations (11 years–adulthood)
	Jerome Bruner	• Learners move through three stages of intellectual development: enactive (manipulation of objects), iconic (visual recognition), and symbolic (abstract reasoning)
Reinforcement	B.F. Skinner	• Learning is a function of overt behavioral change. Behaviors that are reinforced are more likely to recur
Learning Style	Walter Barbe	• Learners process information through one of three preferred modes: visual, auditory, or kinesthetic
	Howard Gardner	• Learners process information through multiple intelligences: visual-spatial, bodily kinesthetic, musical, interpersonal, intrapersonal, linguistic, logical-mathematical, and naturalistic
	Richard Restak	• Cerebral hemispheric dominance has an effect on how learners process information. "Left-brain" learners process information in a logical and sequential manner, and "right-brain" learners process information in an intuitive, holistic manner
Socialization	Albert Bandura	• Students learn by observing the behaviors of others
	Lev Vygotsky	• Socio-cultural interaction plays a fundamental role in learning
Instruction	Robert Gagné	• Nine steps of instruction are necessary to achieve learning outcomes: (1) attention, (2) presentation of learning outcomes, (3) recall of previously learned information, (4) new material, (5) guided practice, (6) application, (7) feedback, (8) assessment of retention, and (9) synthesis and transfer
	Edwin Gordon	• Music learning takes place through an eight-step process that begins with ► aural learning and ► oral imitation, ends with creative experiences and theoretical understanding, and results in ► audiation

sense; (b) ear training: concepts of pitch, scale, and tonality taught through solfège in order to develop the inner ear; and (c) improvisation: concepts of form and meaning taught through free expression using movement, voice, and instruments, in order to develop the capacity for creative expression. Through this approach students develop the ability to respond immediately and creatively to music.

- Zoltán Kodály (1882–1967) was a Hungarian music educator, composer, and ethnomusicologist. The *Kodály* approach was developed in the mid-twentieth century as a result of his belief that music was for everyone, as well as his desire to raise the quality of music education in Hungarian schools. Kodály, his colleagues, and his students developed the Kodály approach, which incorporates the goals of instilling the love of music in every student, developing each student's innate musical abilities, facilitating the development of cultural identity through the use of folk music, and enabling every learner to become musically literate. The Kodály approach is characterized by the use of (a) traditional folk music and dance, (b) unaccompanied singing, including the use of solfège and hand signs in order to develop inner hearing, (c) rhythm duration syllables, and (d) sequential activities leading to development of music literacy.
- The *Orff-Schulwerk* approach was developed from the ideas of German composer Carl Orff

(1895–1982) and colleague Dorothy Gunther, who together founded the Guntherschule in Munich in the 1920s, in order to provide a learning environment for integration of the performing arts of music movement, speech, and drama. After the destruction of this school in World War II, Orff collaborated with music educator Gunild Keetman through radio broadcasts with children, in order to restore the idea of integration of the arts. The popularity of these broadcasts led to the creation of the Schulwerk: five volumes of chants, songs, and instrumental pieces for children. The overarching goal of the Orff-Schulwerk approach is musical learning, experience, and expression, accomplished through the exploration of space, sound, and musical form. Learning experiences are designed to nurture student development of musical skills and understanding, and comfort with active music making, including singing, moving, playing instruments, use of speech in rhythmic and dramatic contexts, improvising, and composing. Orff-Schulwerk is often referred to as "elemental" music making, meaning that the materials used are simple, basic, natural, and relevant to the child's world of thought, fantasy, and play. This elemental music making includes folk music and poetry, and is frequently accompanied by simple pitched percussion instruments developed by Orff for use with children.

- Japanese violinist Shinichi Suzuki (1898–1998) developed the *Suzuki* or *mother-tongue approach*, based on his belief statement that, "Musical ability is not an inborn talent but an ability which can be developed. Any child who is properly trained can develop musical ability, just as all children develop the ability to speak their mother tongue. The potential of every child is unlimited." Suzuki's goal was not simply to develop professional musicians, but to nurture loving human beings and help develop each child's character through the study of music (SAA 2010). The Suzuki approach is an instrumental music approach, in which instruction begins at a young age. Parents accompany children to lessons, and take an active part in the learning process. Children learn aurally before learning to read music. Technique is taught through musical pieces, which are repeated frequently as students perform individually and in groups.

Later Developments in Music Instructional Methods

Newer methods of music instruction have emerged from the need to customize music education to be congruent with changing patterns and values in society. The following methods are some of the best-known newer methods; however, others exist and continue to emerge.

- The *Comprehensive Musicianship Through Performance* (*CMP)* approach was initiated in the United States through the sponsorship of the Ford Foundation. CMP developed out of the desire to improve musical understanding in performance-based music classes through the incorporation of broader, more holistic learning experiences in each lesson. Through this approach, students examine different musics through common structural elements and concepts. Learning experiences consist of performing, listening, analysis, critical response, reflection, composition, conducting, arranging, historical perspective, and improvisation.
- The *Education Through Music* approach, developed in the 1960s by American music educator Mary Helen Richards, is a holistic adaptation of the Kodály approach in order to make it more relevant to North American instructors, students, and school curricula. Its overarching goal is to promote the well-being of children. Sub-goals are to promote language development, social skills, listening skills, intellectual growth, literacy, physical coordination, self-esteem, musical development, and imagination, while reducing bullying, aggression, inattention, and impulsiveness. Musical goals include (a) development of aural skills through folk songs and singing games from the British Isles and the United States, (b) movement activities to promote understanding of rhythm and musical form, and (c) pattern recognition to prepare children for sight-reading.
- In the 1970s, American music educator Edwin Gordon (b. 1928) began to explore the musical development of very young children, resulting in the development of his *Music Learning Theory* a comprehensive method for teaching audiation, or the ability to think music in the mind with understanding. Gordon believes that through audiation, students can make greater meaning

from music, with the primary goal of Music Learning Theory being the development of tonal and rhythm audiation. This approach is characterized by an eight-step hierarchy of instruction that begins with aural skills and listening, progresses through the development of music literacy skills and improvisation skills, and culminates in theoretical understanding (Campbell and Scott-Kassner 2010).

- The *Music in Education* method was created in the 1980s by the Yamaha Corporation in response to the rapid growth of technology and its emergence in education. This approach promotes computerized MIDI (Musical Instrument Digital Interface) keyboard labs as substitutes for traditional general music classroom settings, and posits that students can still participate in traditional general music activities such as singing, movement, and listening, but can also add the experience of technology-based composition. Students progress at their own pace through a prescribed curriculum.
- The *Weikart Movement Sequence* is frequently incorporated in the teaching of movement activities within other methods of music instruction. This approach was developed by Phyllis Weikart, an American physical education teacher, from her belief that many people are not successful in movement activities because they have not learned to keep a steady beat. Her movement learning sequence is based on the connection between language and movement, and consists of the following four steps:
  1. Language only: Saying the movement steps in rhythm
  2. Language + movement: Saying the movement steps in rhythm as the movement is performed.
  3. Language + movement: Whispering the movement steps in rhythm as the movement is performed.
  4. Movement only: Thinking the movement steps in rhythm as the movement is performed.

Cross-References

► Beliefs About Learning
► Cognitive Psychology of Music Learning
► Constructivist Learning
► Instrumental Learning in Music Education
► International Perspectives in Music Instruction and Learning
► Learner-Centered Learning
► Multicultural Issues in Music Instruction and Learning
► Music and Learning
► Research Methods in Music Instruction and Learning
► Social Psychology of Music Instruction and Learning

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Music Learning Over Time

► Developmental Psychology of Music

Music Methodologies

► Music Instructional Methods

Music Pedagogies

► Music Instructional Methods

Music Technology

► Technology in Music Instruction and Learning

Music Therapy

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Definition

Music therapy is the intentional use of music and musical experiences by a professional music therapist to enrich human life; alleviate human suffering; enhance physical, cognitive, emotional, and social functioning; and promote processes of normal development and self-actualization. Music therapists work with individuals with and without disabilities, and they work with individuals in private sessions, small groups, and community contexts.

Music therapy is practiced globally with professional associations devoted to its advancement in over 40 countries. In many of the countries with a professional infrastructure devoted to music therapy, music therapists are eligible to receive licenses and certifications that are recognized by various governmental agencies. For example, in the USA, music therapists can earn board certification by passing a national certifying examination and obtain various licenses as counselors and psychotherapists on a state-by-state basis. Because music therapy is a dedicated course of study from the undergraduate through doctoral levels, and because there is such a developed infrastructure of professional regulation internationally, the professional practice of music therapy is limited to those interventions performed by a recognized professional. Hence, the term does not encompass any and all beneficial uses of music, even when these uses are implemented by health care professionals such as nurses, social workers, or medical doctors.

One of the reasons that this definition is so broadly constructed is because the designation *music therapy* defines an area of practice not by its intended results but by its medium of intervention. This is different from related disciplines such as psychotherapy, speech therapy, or physical therapy. In each of these cases, the label reflects the targeted area of clinical change. In contrast, the fact that music therapy is defined by its medium of intervention means that the practices of music therapists cut across an extremely wide range of areas in human services.

Defining music therapy is such a complex and evolving task that Kenneth Bruscia (1998) has devoted an entire book to this topic. His revised definition follows: "Music therapy is a systematic process of intervention wherein the therapists help the client to promote health, using music experiences and the relationships that develop through them as dynamic forces of change" (Bruscia 1998, p. 20). While this definition is probably the one that is most widely used internationally, the profession has undergone significant change in the 12 years since its publication, thus necessitating the somewhat broader definition at the beginning of this entry.

Theoretical Background

Music has been used to promote emotional, spiritual, and physical well-being since the dawn of history, and it continues to be used in this way by individuals such as shamans and healers in non-technological societies. The origins of the modern profession of music therapy date back to the early twentieth century. While there were fledgling efforts to build a modern profession and practice during the first half of the century, it was not until the second half of the century that these efforts took root.

Beginning in the 1940s, in both the USA and the UK, the early development of the profession was driven by large numbers of veterans of the Second World War who suffered emotional and physical injury, and who were populating hospitals and clinics. Volunteer musicians noted significant (if anecdotal) health benefits, and the need for professional training and regulation soon became apparent. Music therapy experienced rapid growth throughout the second half of the twentieth century as it became disseminated throughout the world. As music therapy became a recognized discipline with academic degrees and professional organizations and credentials, Ansdell (2002) notes that it took on five characteristics that distinguished it from the proto-music therapy forms that developed during the first half of the twentieth century: (1) a change from exclusively receptive methods to participatory ones, (2) a use of improvisation to allow spontaneous joint music-making, (3) an emphasis on the relationship between therapist and client that was modeled after other forms of therapy, (4) emphasis on individual sessions, and (5) allying with extrinsic medical and therapeutic theory for both explanatory and legitimizing purposes.

The clinical practice of music therapy generally does not require the client to have special musical skills or training. This may be more obvious when interventions involve receptive forms of music or singing. When music therapy interventions involve the client as an active participant in making music, music therapists generally employ instruments that, while expressively rewarding, do not require advanced skills to play, such as drums, cymbals, gongs, and various forms of pitched (tonal) percussion instruments. In addition, some standard instruments that do not require years of training to produce a pleasing tone can be adapted for use in music therapy, such as the piano and guitar. The important point is that music therapists generally play music *with* people, not *for* them, a common misconception held by people unfamiliar with the profession.

Although it is relatively small profession, there is an extremely wide variety of clinical music therapy applications. For example, while there are approximately 5,000 board-certified music therapists in the USA, they report ongoing clinical work with approximately 50 different clinical populations in approximately 50 different types of work settings. In spite of this great diversity, Bruscia's (1998) empirical examination of the profession revealed six broad areas into which existing music therapy practices could be subsumed based upon their common clinical focus: the didactic, medical, healing, psychotherapeutic, recreational, and ecological. For example, music therapists who conceive of their work as an in-depth form of personalized treatment and who work with emotionally traumatized individuals would be in the psychotherapeutic area; music therapists whose focus includes increasing immune system response or enlarging the range of motion of a damaged limb would have their work classified in the medical area. Each of these six areas has music therapists who work in very different ways to very different ends and who lean on a wide variety of sources of theoretical support for their work.

The earliest theoretical influences in music therapy – from the mid-1940s through the late 1960s – were derived from various strains of psychoanalytic and psychodynamic thinking. While this psychodynamic thinking remained predominant through most of Europe and South America, in the USA behaviorism became a dominant theoretical foundation beginning in the 1970s through the 1990s. One reason for this is that while music therapy practice was primarily implemented as a form of psychotherapy in the former areas, in the USA music therapy was being extensively applied in other areas such as schools, medical facilities, and facilities for individuals with developmental delays. There are other historical factors involved in this theoretical evolution, primarily related to the fact that the profession of music therapy was heavily influenced by educational organizations and behaviorism dominated so many areas of psycho-social care beginning in the 1970s.

In the 1960s and 1970s, fully developed models of music therapy practice began to emerge. At the World Congress of Music Therapy in 1999, five such international models were recognized: Analytical Music Therapy (Preistley 1994), Behavioral Music Therapy, Benenzon Music Therapy (Benenzon 1981/1997), Guided Imagery and Music (Bonny 2002), and Nordoff–Robbins Music Therapy (Nordoff and Robbins 2007). The criteria for recognition of these models were that each had to be practiced internationally and have its own approach to treatment, clinical training, and research. The theoretical influences of Analytical Music Therapy and Behavioral Music Therapy are noted in their names, and Benenzon Music Therapy is also based on psychoanalytic thinking. The approaches of Guided Imagery and Music and Nordoff–Robbins Music Therapy are more firmly anchored in humanistic and transpersonal psychology. With the exception of Behavioral Music Therapy, each of the other four models was created by a single visionary individual or team.

In the mid-1980s, some theorists in music therapy began articulating their dissatisfaction with the use of theory imported from other domains of inquiry and began arguing for indigenous theory (Aigen 1991). These authors argued that the description and explanation of music therapy phenomena through non-musical theories imported from psychology and/or education fundamentally distorted the nature of these phenomena. At the same time, the hegemony of the positivistic views on research with its attendant reliance on exclusively quantitative models was also challenged. It was argued that the underlying foundations of creative, improvisational, and music-based forms of practice were incompatible with the philosophy underlying positivistic forms of quantitative research. Constructivist epistemologies began to be employed as a foundation both for clinical practice and research.

In the first part of the decade after the year 2000, music therapy theorists began to directly apply ideas and values that were grounded in the philosophical critiques from the 1990s. These included music-centered (Aigen 2005) and music-based models (Garred 2006), and approaches that took more cognizance of the social, cultural, and other contextual factors in therapy, such as culture-centered music therapy (Stige 2002), community music therapy (Pavlicevic and Ansdell 2004), and humanities-based music therapy (Ruud 2010). While representing a diversity of approaches, the aforementioned models have in common a strong reliance on the structures, processes, and contexts of music-making in their rationales and explanations for the value and efficacy of music therapy. They also tend to focus more on enhancing client strengths and abilities rather than remediating disabilities or deficits, and thus tend to be resource-oriented and focus on client empowerment (Rolvsjord 2004). They also work under a greatly expanded notion of what constitutes a legitimate focus of music therapy to work to include things such as improving the well-being of communities (circumstantial and otherwise) and to address problems of social justice.

In contrast to these music- and socially-based theories, there has been a strong impetus in music therapy to employ a medical model of treatment that is more prescriptive in nature and that is based upon standards of experimental research. This desire was first manifest in the support for behavioral approaches and recently it has manifested as a movement to ground all music therapy treatment in brain science (Thaut 2000; Taylor 1997). The current drive towards evidenced-based medical practice throughout much of the Western world is providing further impetus for this emphasis on the medical model of music therapy grounded in neurology and supported by research characterized by randomized control trials.

Important Scientific Research and Open Questions

Music therapy has been demonstrated to achieve important health benefits in the areas of cognition, emotion, social interaction, motor skills, and physiological and neurological functioning. Such findings can be found in published meta-analyses of research in music therapy. A truism in music therapy that has driven its dissemination since the post-World War II era is that clients of all types are able to circumvent areas of disability while engaged in music. A few examples of this phenomenon will illustrate the types of questions most relevant for music therapy research: autistic children who cannot communicate verbally and who are said to have trouble distinguishing the foreground and background of their perceptual and social worlds are able to engage in interactive and responsive antiphonal improvisations with their therapists while discerning and responding to the alteration and embellishment of musical themes; individuals with psychiatric illnesses resulting in thought disorders are able to internalize and relate through musical forms; individuals with verbal impairments due to stroke or other neurological impairments are able to sing words that they cannot speak; individuals with motor impairments are able to move in more fluid and intentional manner while playing music; and individuals with severe dementia can recall and sing songs from their youth, in spite of not being oriented to the present day and unable to recall events from the previous day. The common phenomenon here is that clients with various types of cognitive and affective deficits are able to engage with music in a way that indicates a level of cognitive and affective functioning that is not revealed through other verbally based interactions.

On the neurological level one area of research involves investigating how the human interaction with music can restore damaged neurological pathways or create new pathways where none existed. This line of investigation, while certainly important, begs the question of what is happening on a functional level in the areas of human cognition and affect that orients and motivates the individual with a disability toward musical interaction and allows that person to function more fully. There is clearly a "chicken and egg" dilemma here that involves the relationship between neurological and functional changes. This focus on the relationship between music therapy and brain science is in an incipient stage of development, however, it appears to be something that will be quite fruitful in the coming years.

In response to the conventional wisdom in music therapy regarding the way in which clients are able to circumvent areas of disability while involved in music, music therapy theorists have embraced a new conception of musical competency as something that human beings *do* rather than as something that they *know* through a form of propositional knowledge. Hence the terms *musicing* (derived from the work of David Elliott) and *musicking* (derived from Christopher Small) have gained great currency in the professional literature as they emphasize this active form of knowing. The concept of musical interaction as field of human knowledge is consistent with the epistemological viewpoints of authors such as Michael Polanyi (personal knowledge) and Donald Schön (reflection-in-action).

One final area of epistemological significance is the recent interest in the application of the schema/metaphor theory of Lakoff and Johnson (1980) in music therapy. An important aspect of Lakoff and Johnson's perspective is that much of human cognitive functioning rests upon the existence of core schemas that originate in the human being's experience as a material body in a three-dimensional world. The same schemas that underlie cognitive functioning – such as verticality, source-path-goal, and container – operate in the domain of music and are, in fact, necessary for the experience of sound as music. In other words, to even hear a series of tones in a melody as moving through a series of vertical positions in a metaphoric space, it is necessary to employ the cognitive schema of verticality. Current investigations in music therapy (Aigen 2005) are beginning to examine two important questions in this area: (1) When cognitively- and motorically-impaired individuals are able to respond and interact through music, what schemas are implied by their mode of musical acting? (2) Is it possible that music can provide a virtual space for individuals with cognitive and motor impairments to first develop the schemas that are typically developed by infants and toddlers as they gain control over their own motor functions and are able to intentionally move through space? For example, it is possible that the source-path-goal schema is developed when infants first learn to crawl and can now control their movement toward a goal in space. Yet this same schema is implied in being able to perceive tonal and harmonic motion in music. Perhaps the dynamic field of tonal interaction is processed by humans in a way that the concept of source-path-goal can be developed through the motion of tone in a metaphoric space, much as the infant develops the same schema through controlling motion in physical space.

Cross-References

- ► Abilities and Learning: Psychomotor Abilities
- ► Action Schema(s)
- ► Anticipatory Schema(s)
- ► Embodied Cognition
- ► Epistemology of Learning
- ► Implicit Knowledge
- ► Infant Learning and Development
- ► Learning by Doing
- ► Motor Schema(s)
- ► Schema Development
- ► Schema(s)
- ► Tacit Knowledge
- ► Virtual Change Agents

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Music Violence

► Media Violence Effects on Learning

Musical Expression

► Music and Language Learning

Musical Interpretation

► Music and Language Learning

Musical Maturation

► Developmental Psychology of Music

Musical Nuance

► Music and Language Learning

Myers–Briggs Type Indicator (MBTI)

► Jungian Learning Styles

Myside Bias

► Divergent Probabilistic Judgments Under Bayesian Learning with Nonadditive Beliefs

Myth

► Metaphor Therapy