Theory Construction

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Synonyms

Scientific discovery

Definition

Theory construction is a process, i.e., a set of state changes by an autonomous agent, or by an organism composed of several autonomous agents. In the first case, we may recall the approach of Pierce (1931) that considers three logical operations (inference rules) on a knowledge base, i.e., a set of propositions asserted to be valid: abduction, deduction, and induction. *Abduction* generates new hypotheses from which *deduction* derives predictions to be confirmed by experience. The confirmed hypotheses are structured by *induction* into laws of general validity. A similar way to describe the life cycle of theory construction within a single agent is to say that the real world asks the agent for a concrete solution in a *single instance case*, then the solution is *abstracted* in order to identify laws that are more general; finally the abstracted solution is applied to other classes of instances of the abstract problem, i.e., it is *generalized*. The interplay of these operations in one single autonomous (artificial) agent is widely modeled in the work on machine learning.

The second social scenario – communicating agents learning by exchanging messages – is less easily formalized but probably more realistic when describing human learning. In this article we give support to the conjecture that the process of construction of knowledge in science (theory construction or scientific discovery) and human learning is an interactive human process of a social nature that presents profound similarities and relations with each other so that we may profit from advances in one domain to infer properties of the other one and the reverse. In this approach we are strongly influenced by constructivism (Piaget 1970) and social constructivism.

Theoretical Background

The previous century has been characterized by a *constructivist approach to science* (Zalta 2011). Knowledge construction in any science was strictly associated to proof and validation (Popper 1959). Obviously, proof and validation in history, for instance, is not the same as in mathematics and, in turn, not the same as in physics or biology. Nevertheless, all these proof-and-validation processes require to possess a critical mind as well as to exercise a critical approach knowing that proofs and validations *have to be accepted* by others. Theory construction is then the result of a *social game* that enables the historical development of newborn theories that progressively focus their own validation domain. In more general terms, the scientific activity is considered as a social activity influenced, as all the other ones, by pressures of the contemporaneous leading powers (Kuhn 1962; Latour 1987).

The end of the previous century is marked by an evolution of *reductionism.* Reductionism can either mean (a) an approach to understanding the nature of complex things by reducing them to the interactions of their parts or to simpler things or (b) a philosophical position that a complex system is nothing but the sum of its parts, and that an account of it can be reduced to accounts of individual constituents. Problem solving is not considered anymore just as consisting of decomposing each problem into a finite set of subproblems and composing the solutions. Rather, the *holistic, situated* approach to problem solving requires one to integrate (or make interoperable) the partial results validated by different scientific disciplines. Reductionism and holism seem today complementary approaches. For instance, understanding and forecasting phenomena related to the global warming problem requires to consider the planet and model *simultaneously*, for example, their physical, chemical, biological, and social properties. A regulation rule influencing human behavior acts modifying the actors thus the observed system. According to the pioneer ecologist Francesco Di Castri, for instance (Di Castri and Hadley 1988),

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one of the major scientific bottlenecks to natural resource management was the lack of a holistic approach bridging ecology (in fact, according to his views, social ecology with a strong emphasis on human impact) and the natural sciences. We are facing what people call a complex system with feedback. From a practical viewpoint, reductionism supports human learning by disciplinary subjects and toy problems, while a holistic view supports learning by solving realistic inter-, trans-, and multidisciplinary problems.

Important Scientific Research and Open Questions

Scientific knowledge is built and communicated by means of *interactions* among scientists and between scientists and all other human beings. Several interaction communities are formed and dissolved each having properties that are different one from another. A scientist does not process his/her theories *alone*, but rather he/she is guided by critics of his/her pairs on a scientific production offered as a contribution to the solution of problems identified within a scientific context where publications already exist. A well-trained researcher should be able to enact successfully a problem-solving process on old and new problems within a scope limited by the discipline of expertise. The training requires exercise but training and practice are intertwined all life long, not separated in temporal phases, so that we may treat scientists as lifelong students and teachers at the same time.

The interactive view does not assume that each of the interacting partners have the same knowledge, language, goals, plans, strategies, tactics, intentions, preconceptions, assumptions, misconceptions, etc. In order to hopefully converge to an agreement, arguments and counterarguments are discussed and exemplified in a *social, interactive negotiation*. Communities exchange messages according to patterns and rules that historically have been studied in sociolinguistics: *pragmatics*, which is the science of understanding the relations between messages and the state of the actors producing and receiving those messages, and *rhetoric*, which is the art of convincing a partner about an argument or evoking emotions into a partner, are the disciplines that deal best with human interaction. In the most interesting case, the rhetoric game of interacting for negotiating meaning occurs between and among actors belonging to different viewpoints/disciplines, thus offering inter-, multi-, and transdisciplinary scenarios of *collective intelligence*. Recently, emotions and personality traits have entered the scene as a mean to understand individual intelligence; thus we expect them also to be at the core of phenomena of collective intelligence.

Formal theories of interactive *learning* study different approaches of knowledge construction and their effectiveness. It is usually hard to say that one approach is correct and the other ones are wrong; often it is the case that they are complementary. Let us consider foreign language learning by practice: after a while, the learner's performance improves and his/her mistakes diminish. This learning is accelerated if the instructor confirms (or not) the correctness of his/her sentence, or either when the instructor shows the apprentice the incorrectness of a grammatical form by showing a counter example. Such training *by practice* is also common in learning of sports or in learning of artistic skills when the trainee is required to adopt complex practices without necessarily justifying them as theories. Any learning needs practice: the trainer should define the exercises adequate for the learner to untie the body and the mind. Similarly, the researcher's work requires a practice to learn how to be creative. But practice and supervised learning without creativity and autonomous rational thinking seem to concern only a minor part of the complex knowledge and skills required for coping with realistic problems.

Where does *creativity* come from? Sometimes it emerges from a coincidence; often it is the fruit of a surprise (unexpected event) assuming the mind is well prepared to that event. The history of sciences is full of discoveries emerging from chance, manipulation errors, even from the innocent viewpoint expressed by a novice. Such *serendipitous events* look quite similar to learning as a side effect of interaction: something that happens even if we can neither forecast its occurrence nor explain its origins.

We will reinterpret *multi-, inter-, and transdisciplinarity* as modalities of collective behavior of the social game of theory construction that we claim to be similar to human learning. Assume a "service-oriented view" of such a social interaction: the one actor *produces* a statement and the other one *consumes* it, either for progressing in his/her own scientific construction, or for demonstrating/refuting the validity of the proposed statement. Under the hypothesis that the two actors come from different disciplines (or sub-domains of knowledge) one may have several composite situations – interaction patterns – that explain the nature and complexity of the holistic view previously identified to be a foundation of current scientific progress as well as modern learning processes.

At the basis of each of those situations there is the fact that "Real-world problems may not respect discipline boundaries" (Popper 1959) while scientific communities are made of actors that mainly master a single discipline, including the lexicon and the methods. Here is the crucial challenge for the future of science as well as innovation and, simultaneously, human learning: How to exploit disciplinary convictions, viewpoints, rules, and jargon when many of them should interact synergically. Hereafter is a simple, though significant preliminary classification that adopts the above identified classification criteria.

Multidisciplinarity: each actor uses statements proved by his/her (multidisciplinary) community in his/her own problem's statement and argumentation.

Interdisciplinarity: each actor exploits in her/his proof statements proved by another community. The principle of interdisciplinarity is to admit as axioms some results proved by other communities that one cannot prove by himself. An interdisciplinary approach is required when there is no discipline omniscient and omnipotent able to solve the problem without intervention from others.

Transdisciplinarity: actors propose some hypothetical statements to other communities that trigger inter- or multidisciplinary work (Piaget 1970).

Each of these interaction scenarios may be mapped to many concrete situations (called also business processes) of theory construction and scientific discovery, but also of technological innovation. In human learning, similarly, the game of collective construction of knowledge is very clearly influenced by synergies between and among actors each representing different disciplines, viewpoints, and interests.

Finally, the interactive construction of scientific theories can be viewed as an activity intertwined with two kinds of learning: one is supervised by the teacher or master and implies the acquisition of practical skills; the other is unsupervised as it is concerned with the communication of knowledge in the form of documents that have to be evaluated by pairs.

Since both the process of creative discovery in science and learning in all its facets present those quite similar properties, we may assume that they are related to each other, so that advances in understanding each of the two may be profitable for the other one and the reverse.

Cross References

► Abductive Reasoning
► Advanced Learning Technologies
► Learning as a Side Effect
► Networked Communities

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