Theory Construction

Jean Sallantin, Stefano A. Cerri

► To cite this version:

Jean Sallantin, Stefano A. Cerri. Theory Construction. Encyclopedia of the Sciences of Learning, Part 20, Springer, pp.3311-3314, 2012, 10.1007/978-1-4419-1428-6_60 . lirmm-00670584

HAL Id: lirmm-00670584

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Corresponding Author	Family Name	Sallantin
	Particle	
	Given Name	Jean
	Suffix	
	Division	LIRMM: Laboratory of Informatics, Robotics and Microelectronics
	Organization	University Montpellier2 & CNRS
	Address	161 rue Ada, 34095, Montpellier, Cedex 5, France
	Email	js@lirmm.fr
Author	Family Name	Cerri
	Particle	
	Given Name	Stefano A.
	Suffix	
	Division	LIRMM: Laboratory of Informatics, Robotics and Microelectronics
	Organization	University Montpellier2 & CNRS
	Address	161 rue Ada, 34095, Montpellier, Cedex 5, France
	Email	cerri@lirmm.fr

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Theory Construction

[Au1] 3 JEAN SALLANTIN, STEFANO A. CERRI
4 LIRMM: Laboratory of Informatics, Robotics and
5 Microelectronics, University Montpellier2 & CNRS,
6 Montpellier, Cedex 5, France

7

Synonyms

8 Scientific discovery

9

Definition

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

29 The second social scenario – communicating agents
30 learning by exchanging messages – is less easily formalized
31 but probably more realistic when describing human learn-
[Au2] 32 ing. In this article we give support to the conjecture that
33 the process of construction of knowledge in science
34 (theory construction or scientific discovery) and human
35 learning is an interactive human process of a social nature
36 that presents profound similarities and relations with each
37 other so that we may profit from advances in one domain
38 to infer properties of the other one and the reverse. In this

approach we are strongly influenced by constructivism 39
(Piaget 1970) and social constructivism. 40

Theoretical Background

41 The previous century has been characterized by 42
a *constructivist approach to science* (Zalta 2011). Knowl- 43
edge construction in any science was strictly associated to 44
proof and validation (Popper 1959). Obviously, proof and 45
validation in history, for instance, is not the same as in 46
mathematics and, in turn, not the same as in physics or 47
biology. Nevertheless, all these proof-and-validation pro- 48
cesses require to possess a critical mind as well as to 49
exercise a critical approach knowing that proofs and val- 50
idations *have to be accepted* by others. Theory construction 51
is then the result of a *social game* that enables the historical 52
development of newborn theories that progressively focus 53
their own validation domain. In more general terms, the 54
scientific activity is considered as a social activity 55
influenced, as all the other ones, by pressures of the con- 56
temporaneous leading powers (Kuhn 1962; Latour 1987). 57

58 The end of the previous century is marked by an 59
evolution of *reductionism*. Reductionism can either mean 60
(a) an approach to understanding the nature of complex 61
things by reducing them to the interactions of their parts 62
or to simpler things or (b) a philosophical position that 63
a complex system is nothing but the sum of its parts, and 64
that an account of it can be reduced to accounts of indi- 65
vidual constituents. Problem solving is not considered 66
anymore just as consisting of decomposing each problem 67
into a finite set of subproblems and composing the solu- 68
tions. Rather, the *holistic, situated* approach to problem 69
solving requires one to integrate (or make interoperable) 70
the partial results validated by different scientific disci- 71
plines. Reductionism and holism seem today complemen- 72
tary approaches. For instance, understanding and **[Au3]**
forecasting phenomena related to the global warming 73
problem requires to consider the planet and model *simul-* 74
taneously, for example, their physical, chemical, biological, 75
and social properties. A regulation rule influencing human 76
behavior acts modifying the actors thus the observed **[Au4]**
system. According to the pioneer ecologist Francesco 77
Di Castri, for instance (Di Castri and Hadley 1988), 78
79

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.

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