Critical Thinking as a Tool for the Development of Interdisciplinarity in University Education

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Abstract
In this essay the relationship between critical thinking and interdisciplinarity is examined.

Critical thinking is explained as a multilayer phenomenon that should be examined systematically on interdisciplinary platform. The basic issues linked to an interdisciplinary research of critical thinking are: relations between critical thinking and language, logical and cognitive operations in the process of critical analysis, methods of critical thinking and their anchoring in the methodology of science, the process of critical thinking in relation to personal dispositions and attitudes, possibilities of development and evaluation of critical thinking within educational and learning processes.

An interdisciplinary approach is a synthesis of two or more disciplines that result in establishment of a new scientific discourse, while the knowledge that results from it has an integrative character. Basic goal of interdisciplinary research lies in the deeper level of analysis, creation of a new explanatory frame (research paradigm) and identification of new operative causes. These enable us to offer unified explanation of seemingly heterogeneous phenomena. Meaning and importance of the interdisciplinarity is illustrated through the example of formation and development of cognitive sciences.

Fundament of the education at the level of higher schools or universities should not lie only in the transfer of factual information, but also in intentional and purposeful development of cognitive abilities of students. The ability of critical thinking is one of the interdisciplinary skills. Education in the area of critical thinking is associated with the interdisciplinary approach. Therefore, critical thinking and interdisciplinary approach are contingent on and stimulate each other.

Keywords: critical thinking, interdisciplinarity, research, cognitive science, education

Introduction

The ability to think critically is indicated as a key competence of the 21st century by many authors (compare Halpern, 2003, Huitt, 1995, Thomas & Smoot, 1994, Bowell & Kemp, 2002 and others). Also development in the area of interdisciplinarity can be considered as an important principle participating in massive advancement of science and technology at the beginning of this century. Both of these phenomena are mutually pertinent and contingent on each other. It is the role of university (general or all-embracing) education to reflect systematically both the improvement in critical thinking as well as development of interdisciplinary relations in the frame of scientific-technological study and research. In this contribution we deal with:

1. Defining and clarifying the terms *critical thinking* and *interdisciplinarity*
2. Enlightening the mutually conditional relation between critical thinking and interdisciplinarity, particularly:
   2.1 interdisciplinary research in the frame of critical thinking
   2.2 critical thinking in the area of interdisciplinary research
3. Introducing the critical thinking as a tool for development of interdisciplinarity in the frame of higher education

Relationship between Critical Thinking and Interdisciplinarity

The term *critical thinking* can be described as a set of formal operations that influence the processing of information and reaching the planned goals and desired outcomes. Critical thinking is a suitable tool for work with a set of factual information (in a similar way as Aristotle´s work on logic was called the "pipe organ" of thinking). Critical thinking can be determined either from the epistemological point of view as a logically correct way of thinking (that enables us to distinguish between logically correct and incorrect arguments) or from the practical point of view as a condition for efficient and purposeful action (that is not determined by extreme manipulative tactics). Many definitions of critical thinking are based on this dual understanding of its meaning:

1. Critical thinking as a tool for correct cogitation:

   - *„... active, systematic process of understanding and evaluation of arguments"* (Mayer & Goodchild, 1990, p. 4);
   - *„... ability to analyze facts, generate and organize ides, defend opinions, make comparisons, make inferences, evaluate arguments and solve problems."* (Chance, 1986, p. 6);
   - *„... involving analytical thinking for the purpose of evaluating what is read"* (Hickey, 1990, p. 175);
   - *„... the cognitive competences most relevant to critical thinking are metacognitive rather than cognitive-competencies. In contrast to first-order cognitive skills that enable one to know about the world, metacognitive skills are second-order meta-knowing skills that entail knowing about one's own (and others') knowing."* (Kuhn, 1999, p. 17);

2. critical thinking as a tool for making good decisions:

   - *„... the ability to analyze people's attempts to persuade ... and evaluate whether or not they are giving a good argument."* (Bowell & Kemp, 2002, pp. 2-3);

- *„Critical thinking is the use of those cognitive skills or strategies that increase the probability of a desirable outcome."*(Halpern, 2003, p. 6);
- *„Critical thinking is reasonable and reflective thinking that is focused on deciding what to believe or do."* (Norris & Ennis, 1989, p. 1)
- *„... challenging a claim or an opinion (either one`s own or another person`s) with the purpose of finding out what to believe or to do. "* (O'Hare & McGuinness, 2009, p. 123).

Critical thinking as a tool for processing information can be characterized by its "keystones" - the thought operations. There are some calculations and classifications of these fundamental thought operations in practice; for example, *interpretation, analysis, evaluation, inference, explanation, self-regulation* (Facione, 1990, p. 6); *purposes, question at issue, interpretation and inference, concepts, assumptions, implications and consequences, point of view* (Paul and Elder, 2008); metacognitive monitoring, verbal intelligence, analysis of arguments, testing of hypotheses, estimation of probability and making decisions (Halpern, 2003, p. 20). We propose following way of classification of fundamental thought operations that create and support the ability of critical thinking:

- *Cognitive operations (CO)*: analysis, synthesis, comparison, abstraction, idealization, generalization, concretization, analogy, classification, modelling and others,
- *Formal-logical operations (FLO)*: implication, equivalency, conjunction, disjunction, negation and others,
- *Complex operations of critical thinking (COCT)*: argumentation, evaluation, interpretation, inference (in broader sense), deduction (in broader sense), induction and others.

This system of classification is organized in hierarchical order (from basic cognitive operations up to complex operations of critical thinking). The next two categories are contingent by the first one: so that we are able to understand the FLO and COCT we must be able to master the CO. Difference between CO and FLO lies in the possibility of their formal script. Whilst the formal-logical operations use exact conditions for setting the verity (validity), in case of cognitive operations there is no exact formal algorithm which can serve as a criterion for the verity or validity. COCT deal with the vast informational units what makes them difficult to be identified both from the point of view of their formal algorithm and conditions of their validity.

Critical thinking as a tool for creation of reasoned decisions supports the following abilities: *be open to criticism and argumentation, look for alternatives, take into account the total situation, be well informed* (Ennis, 1985, pp. 46–47); *truth–seeking*, *open-mindedness*, *analyticity, systematicity, critical thinking self – confidence, inquisitiveness and maturity of judgment* (Facione et al., 1995, p.6); *intellectual humility, autonomy, empathy, integrity, perseverance, fair-mindedness, intellectual courage, confidence in reason* (Paul & Elder, 2008, p.15).

The abovementioned abilities and attributes help to transfer critical thinking from the epistemological level into pragmatic one and thanks to this transfer we can apply the outcomes of critical analysis to reach the desirable aim.

Thought operations and personal dispositions are mutually conditioned and create the ability to process information and to reach specified goals. Character and degree of this mutual influence has not been defined exactly so far. Thought operations hand in hand with personal dispositions are developing in the frame of ontogenesis of an individual human being more or less in exactly demarcated phases. Kuhn (1999) defines three forms of so called metacognition (second stage cognition) which condition the human ability to think critically: metacognition (getting to know the process of cognition), metastrategy (development of criteria that are used to judge the validity of cognition) and the form of epistemological attitude of an identifying subject (there are four categories of human attitude towards reality – realist, absolutist, versatile person and evaluating person). Metacognitive strategies are systematically orientated on the cognitive process, on its subject and object, criteria of correctness, error correction and evaluation of cognition of other people. Metacognition conditions the origin and existence of a consistent file of evaluating criteria that are applied systematically, notwithstanding particular object, subject or situation. The possible improvement and implementation of the principles of critical thinking is conditioned by the development of the second degree cognition and the existence of evaluating criteria (p. 23).

According to Piaget and Inhelderová (2010, p. 45-68), any development of cognitive abilities is conditioned by the existence of so called symbolic function which emerges thanks to the developed motor-sensory intelligence at the age of approximately two years. It is based on the ability to present or imagine something, or to create conceptual schemes. Basic principle of the symbolic function is defined by the existing difference between identified and identifying. Complex representative (semiotic or symbolic function) is a crucial condition for the possibility of creation of a symbolic gesture, figurative image and speech. Children usually do not use figurative images in their motor-sensory period. Progressive commencement of new cognitive functions at the beginning of the second year of human life should go along with the child´s capability to imagine the object and consequent ability to create the image of such object when that is not present anymore. Symbolic function goes across phases of so called distant imitation (for example imitative gestures), symbolic or fictional play (pretended sleep) and drawing or graphic visualization (which presents the crossover from play to figurative imagination). This is followed by the visual image (in sense of the interiorized imitation) and the whole process is finally topped by the creation of a language sign. Step by step the imitating act is setting apart from the current context and is becoming a generalized marking symbol – an image in human mind. Mental image is separated from the outer acts and by its generalized and formal nature it becomes the base for further development of higher cognitive functions. Nowadays, interdisciplinarity is being more and more put into effect in contemporary research practice. It is important to define it in relation to multidisciplinarity and transdisciplinarity. The term multidisciplinarity refers to systematic accumulation of knowledge from various scientific disciplines, while the subjects of their research do not overlap and the final outcome of their connection has the additive character and not the integrative one. In case of multidisciplinary research there are some scientific disciplines participating in examination of the common research subject. Accumulation of knowledge is peculiar to this type of approach, borders between particular scientific disciplines, as well as their terminological vocabularies and methodological apparatuses remain mutually exclusive. According to Frodeman (2010, p. 234-245) knowledge obtained through the multidisciplinary

approach is juxtapositional, sequential and coordinated. Cognitive processes in living organisms had been the subject matter for variety of scientific disciplines (philosophy, psychology, linguistics or neuroscience) even before genesis of cognitive sciences, but this type of research was only of multidisciplinary character. There was not any unifying, conceptual or methodological frame (common paradigm) for creation of theories about cognition.

On the other hand, interdisciplinary approach leads to the implementation of a new scientific paradigm which integrates methodological apparatus and terminological vocabulary of different scientific disciplines. Deployment of various mathematical models in the process of explanation the principles of how social or economic sciences work, can serve as a good example (game theory, chaos theory and the like). And what about the implementation of knowledge from the area of nuclear physics in medical diagnoses. Interdisciplinary approach frequently leads to the creation of a new scientific discipline (as it is in case of cognitive sciences, biochemistry, biotechnologies, eco-philosophy and so on).

The aim of interdisciplinary approach is to explore the limits of explanatory frames of different scientific disciplines towards their consecutive approximation. Multidisciplinarity is characteristic by its outer coherence (common research subject), whereby the final goal is to reach as high level of complexity of knowledge as possible. Interdisciplinarity leads us towards deepening of internal coherence (beside common research subject there is an obvious unification of methodology and terminology). Basic goal of interdisciplinary research lies in the deeper level of analysis, creation of a new explanatory frame (research paradigm) and identification of new operative causes. These enable us to offer unified explanation of seemingly heterogeneous phenomena.

In case of interdisciplinary researches, one of the key methodological approaches is so called reductive method. Reductive explanation is about glossing either events, phenomena, attributes and subjects (ontological reduction), or theories, terms, models and schemes (epistemological reduction). Beside this division we can also distinguish between different degrees of scientific reduction: (1) reductions in the frame of the only level (mathematical derivations including approximations), (2) abstract multilevel (inter-theoretical) reductions (explanation of the higher level attribute through the attribute of lower level), (3) spatial multilevel or strong reductions (scientific explanation concentrates on the description of behaviour of elementary particles) (Sarkar 1998, pp. 424 - 434). Inter-theoretical reductions are characteristic feature of interdisciplinary explanation.

"Inter-theoretical reduction is the relation between two different conceptual frames describing the phenomenon itself; nonetheless, sometimes it is confusingly described as a relation between two different attributes of the phenomenon. The very sense of reduction is to show that what we considered to be consisting of two spheres is in fact only one sphere described by two or more different vocabularies." (Churchland, Churchland 1998, p. 69). A good example of inter-theoretical reduction is the heat theory as an average molecular energy or identification of sound with pressure waves spreading across the atmosphere. The most well-known reduction of modern science is the reduction of Newton´s Laws of Motion into the Einstein´s Special Theory of Relativity.

Critical thinking is extremely complex and multilayer phenomenon and that is why we have to examine and explain its principles through the interdisciplinary paradigm. We propose following scheme for the inter-disciplinary research of critical thinking:

1. Critical thinking in relation to language (area of cognitive linguistics)
2. Critical thinking in relation to cognitive and logic (both formal and informal) operations (area of logic, cognitive psychology and information science)
3. Critical thinking in relation to methodology of science (area of the philosophy of science)
4. Critical thinking in relation to personal dispositions and social attitudes (area of the personality psychology, cognitive anthropology, ethics and others)
5. Critical thinking in relation to pedagogy and other educational sciences (area of pedagogy and pedagogical sciences)

In the frame of the first three research areas, the critical thinking is examined from the point of view of its epistemological nature. The key factor here is its cognitive function. That what plays the crucial role in this process are the questions regarding relation between thinking and language, regarding validity criteria for logical-formal thought operations and possibilities for their deployment in the frame of complex (non-formal) operations of critical thinking. Cognitive linguistics is searching for the connection between the structure of language representations, their processing and their neuronal base. One of the up-to-date and quite interesting topics is the issue of the existence of algorithm for cognitive operations (analysis, abstraction, idealization, modelling and the like) which consequently can be simulated by artificial intelligences or by self-learning systems.

The process of critical thinking as an exactly defined way of processing information is based on the methodological progress of science. Scientific method which is the subject matter for the examination in the area of philosophy of science can be generally described in three basic steps: 1. Observation and description of a phenomenon or a group of phenomena; 2. Formulation of a hypothesis that should explain the observed phenomenon through the principle of causality; 3. Based on the predictions in hypothesis, the tests are being created which can either confirm or deny the hypothesis; 4. In the last step, repeatedly confirmed hypothesis is integrated into the system of other confirmed assumptions and laws of scientific theories (Bednáriková, 2013, pp.14-15). Also in case of critical analysis we advance from defining the problem, through collecting the information, inductive or deductive pondering, identifying hidden logical errors or contradictions, up to the eduction of one´s own conclusions.

Scientific explanation has a character of deductive or inductive derivation from two premises: general affirmation (natural law, statistical findings) and description of particular occurrence (initial conditions). By subsuming of concretely described occurrence under the general law we are capable of explaining such occurrence and we can define its cause (why the things happen in the way they do, and not in any different way). Critical thinking advances analogically towards the scientific cognition and explanation. Some conclusions can be deduced from premises (assumptions) based on the logical inference rules, others can be obtained by means of generalization (induction) with certain probability measure.

In the frame of last research field we propose to examine possibilities of systematic development of critical thinking hand in hand with its objective assessment. The issues regarding development of cognitive operations and logical thought procedures of students on one side and also the problems regarding the way of upbringing towards desired personal attitudes and social-culture strategies on the other side play the important role in this process that is closely connected to the sphere of critical thinking (see above). More than any other feature, it is just the pragmatic aspect of critical thinking as a tool for correct (reasoned) process of making decisions and actions that is being emphasised at this place.

Relationship between the critical thinking and the interdisciplinarity can be explained in a following way: critical thinking is a primary interdisciplinary phenomenon that cannot be explained at sufficient level in the frame of explanatory framework of a single scientific discipline. On the other hand, the interdisciplinary research that is rapidly moving ahead in many fields of human cognition nowadays, is strictly conditioned by the abilities of critical analysis, assessment of relevance, terminological clarification, identification of connections and analogies, conception of theoretical models and many others, in other words, it is conditioned by the complex operations of critical thinking. A good example of such mutually conditioned relation between critical thinking and interdisciplinary research can be the origin of cognitive-scientific paradigm in the middle of the 20th century. From the very beginning of philosophical analyses it was the phenomenon of thinking or cognition that was one of the most frequently explained as well as one of the least clarified phenomena. Its multilayer character had been beside the possibility of its adequate understanding in the frame of one terminological and methodological explanatory framework. In the moment of establishment of the cognitive science, scientific discourses from the fields of *theoretical linguistics* (analyzing possibilities for language modelling based on its syntactic rules), *artificial intelligence* (explaining the thinking as a calculating process – algorithm for dealing with symbols), and *experimental psychology* (searching for the possibilities of connection of mental operations with mechanical procedures) created a brand new scientific union (compare Wilson, Keil, 1999, pp.15-36). In the 1970´s a group of other disciplines subjoined the abovementioned fields which were philosophy, anthropology and evolutionary biology. Also cognitive neuroscience played an important role in the whole procedure. Is was moving ahead with giant leaps especially thanks to the invention of displaying methods in the process of brain examination (PET, MRI and fMRI). Nowadays, cognitive science from the point of view of the interdisciplinarity is being systematically unified based on some fundamental axioms. The main goal of cognitive-scientific research is to create empirically testable hypotheses that explain structural and procedural aspects of human cognition. In this context cognition can be understood as a complex of all mental structures and processes of human knowledge and cognition (from sensory perception and behaviour up to the human speech and thinking) and this is what we call the mental knowledge structure. Thinking is in the frame of this paradigm explained simply, but really efficiently: as the ability to process information. Cognitive operations can be understood as the calculations directed by exact algorithms (by sets of rules for procedures of information processing). The outcome is the transformation from one state of cognitive system into another one. Hypotheses in cognitive research must be eventually empirically falsifiable by the observable psychological and neurophysiological facts. This way of explanation of cognitive operations brought an extensive explanatory power to the new theories and the

justness of cognitive-scientific paradigm can be seen also in rapid advance of systems of artificial intelligence and robotics (see e.g. Návrat, 2007).

Conclusion

Fundament of the education at the level of higher schools or universities should not lie only in the transfer of factual information, but also in intentional and purposeful development of cognitive abilities of students. So called metacognitive processes play a crucial role in this procedure. In its frame there are analyses and assessment s of all cognitive processes running. Students must be able not only to memorize new knowledge and information, but also to deal with them in the context and evolve them step by step. They also should systematically and critically monitor and verify their thought operations. Only thanks to the education that repeatedly instigates the ability of critical analysis, evaluation, verification, creation of one´s own information databases, argumentation or prognosis of future impacts, it will always be possible to apply the principles of permanently sustainable development.

One of the most important attributes of a thinking human being is the effort to think in a broad context of occurrences and facts. This so called systematic approach means preferring the holistic perspective and circular causality to the linear one. An example of this type of causality is the feedback loop that can be illustrated through the relation between a predator and its prey. An over reproduction of predators causes less and less amount of prey per one predator and this consequently leads to decrease in the number of predators. This again causes the effect of an over reproduction of the hunted animals what leads to the increment in the number of predators. (Leonard, Beer, 2003). Application of the systematic approach enables identification of new relationships, connections and causalities and it presents the fundament for the implementation of interdisciplinary approach.

In this contribution we have tried to clarify the interdisciplinary character of critical thinking. Research in the area of critical thinking includes the scientific fields of cognitive linguistics, logic, cognitive psychology, information science, philosophy of science, personality psychology, ethics and educational sciences. So, if we want to improve the ability of critical thinking in the frame of the university education, we inevitably must “work” on more scientific fields at once. On the other hand, if the subject matter of the education is targeting at the cognitive and metacognitive operations, their further development is possible in any particular area of education since it deals with the improvement of formal processes and not with the factual knowledge.

Critical thinking, its improvement and the process of upbringing in the frame of university education goes hand in hand with the development of interdisciplinarity. It leads students towards more efficient division and classification of obtained information in sense of systematization of knowledge from different academic subjects or disciplines. This way of thinking presents a fundamental condition for implementation of interdisciplinary approach which nowadays seems to be most fruitful and very inventive.

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