Cognitive stages in rational thinking - toward human technology

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"Cogito ergo sum" (French: Je pense, done je suis; I think, therefore I am), Rene Descartes

ABSTRACT

The main idea behind this research paper is that modern information and communication technology could be better made to serve human beings, if we could specify more precisely the process of human thought and action.
The cognitive stages of rational thinking has been studied from the user interface and product point of view but there does not seem to be any generally accepted model for the dynamics involved in cognitive stages in literature.
In addition, a few studies have investigated the cognitive stages in rational thinking process from human centric point of view, i.e. how the skills are actually learned.

INTRODUCTION

First, I shall provide short historical preview of between human thinking, learning and performance.
Jean Piaget (1896-1980) believed that the process of thinking and the intellectual development has two on-going processes: assimilation and accommodation. There is assimilation when a child responds to a new event in a way that is consistent with an existing schema. The schema describes as pattern of thought or behavior that organizes categories of information and relationships amount them. There is accommodation when a child either modifies an existing schema or forms an entirely new schema to deal with a new object or event. DiMaggio [6]. It seems that the accommodation in modern society is becoming more important than assimilation.
Alan Turning (1912-1954) was pioneer in the development of theoretical computer science. The Turing test is a test, developed by Alan Turing in 1950, of a machine's ability to exhibit intelligent behavior equivalent to, or indistinguishable from, that of a human. Turing proposed that a human evaluator would judge natural language conversations between a human and a machine that is designed to generate

human-like responses.

Human performance by Fitts & Posner (1967) was a textbook designed to introduce students to a new field of psychology. The field involved the quantitative measures of human capacities to perceive, attend, reason and act.

First, Fitts &Postner (1967) outlined a theory of learning involveda) cognitive, b) associate and c) autonomous stages. In a cognitive phase during which the performer develops a mental picture and fuller understanding of the required action to form an executive program, an associative phase during which the performer physically practices the executive program learned in the cognitive phase and an autonomous phase during which the performer learns to carry out the skill with little conscious effort.

Second, Fits, described a quantitative theory of human movement control. The time to begin a movement was related to the uncertainty of the event and the compatibility of the codes relating stimulus to response, which the rate of movement was function of the information it generated.

Stuard Card [4] and his colleagues proposed the first stimulation of a user for HCI in 1983 (GOMS), where a designer could evaluate an interface by simulating how users perceive, think and act when completing tasks. Subsequent models (such as ACT-R) extended this modeling to consider factors such errors and learning. However models become difficult to use and extend. To aid practitioners, mathematical simplifications such as KLM and GLEAn and interactive modelling environments (like CogTool and Distract-R) were developed, but these were not combined with algorithms that could generate designs. Oulasvirta [14]

Nowadays, in the field of cognitive science, researchers has focused to study human thoughts using neuroscience i.e. neural imaging to discover cognitive stages of rational thinking. For instance multi-voxel pattern recognition techniques combined with Hidden Markov models has be used to discover the mental states that people go through in performance a task [1,2]. However, most of the cognitive science experiments are still conducted in laboratory settings.

In the year 2018, Alan Turning test is still failed by all intellectual personal assistance such as Apple's Siri, Amazon's Echo and Samsung's Bixby. Therefore, to continue Alan Turnings work and to develop more human like intellectual personal assistance, we need to focus our effort to study more deeply the interaction and human thinking models in the context of most developed artificial intelligent applications (Siri, Echo, Bixby) and robotics such as Watson Pepper.

1.1. COGNITIVE MODELS OF LEARNING

Here I shall present four cognitive models of learning i.e. cognitive stages of rational thinking when the human is taking a new artifact in use.
Anderson & Fincham [1,2] introduced the Adaptive Control of Thought-Rational (ACT-R), which is a cognitive architecture: a theory for simulating and understanding human cognition. Researchers working on ACT-R strive to understand how people organize knowledge and produce intelligent behavior. As the research continues, ACT-R evolves ever closer into a system which can perform the full range of human cognitive tasks: capturing in great detail the way we perceive, think about, and act on the world.
Anderson & Fincham [1,2] conducted a study that looked at the cognitive stages participants engaged in when solving mathematical problems. These stages included encoding, planning, solving and response. The study determined how much time participants spend in each problem solving stage when presented with mathematical problem. Multi-voxel pattern recognition analysis and Hidden Markov algorithms models were used to determine participants' problem solving stages. The combined method identifies both the mental states and how their duration vary with experimental conditions. Result of the study showed that the time spend in the planning stage was dependent on the novelty of the problem. The time spend in the solving stage was dependent on the amount of computation needed to produce a solution once a plan is devised. Lastly, the time spent in the response stage was dependent on the complexity of the response required by the problem.

Encoding → Planning → Solve → Response

Figure 1. Cognitive stages with participants solving mathematical problems. Anderson & Fincham [1,2]

Anderson & Fincham [1,2] states that discovery of encoding, planning, problem solving, and responding states was not surprising and was anticipated in a previous cognitive model for the task. However, there were a number of surprising aspects of these states not anticipated:
At the end, according to Anderson & Fincham [1,2] memory has the ability to encode, store and recall information. Procedural memory, made of productions. Productions represent knowledge about how we do things: for instance, knowledge about how to drive bicycle. At each moment, an internal pattern matcher searches for a production that matches the current state of the buffers. Only one such production can be executed at a given moment. That

production, when executed, can modify the buffers and thus change the state of the system i.e. change the behavioral model of human being.
The second Elliott et al. [10] cognitive model of learning found that the process of cognitive thinking is linear with the following causalities: a) transparency of operations, b) transparency of purpose, c) accommodation and d) accomplishment.
In other words, transparency of operations and transparency of purpose lead to a sense of accommodation and finally to the sense of accomplishment. In addition, the poor transparency of operations and purpose lead to increased effort and longer task completion times. In other words, transparent design minimizes cognitive demand on the users [16]
The third one is Gagne's et al. [7] cognitive model of learning, which includes: the motivation (expectancy), apprentice (attention, selective perception), acquisition (coding, storage entry), retention (memory storage), recall (retrieval), generalization (transfer), performance (responding) and feedback (reinforcement) phases.
Gagne's et al. [7] model of learning is described in psychological and cognitive science point of view. Gagne's et al. [7] model of learning is linear and it emphasis the role of motivation in learning process. The users expectancy i.e. presumptions toward the task or artifact is seen important element, which effect positively or negatively the other phases of learning.
The forth cognitive model of learning is presented by Laakkonen (2007) involve six phases: 1) information search, 2) data collection, 3) knowledge management, 4) knowledge form, 5) knowledge build and 6) result of action. In learnability perspective: information search and data collection phases are the most demanding and most time consuming, when taken the new technological artifact in use.
In the table 1 the four cognitive models of learning is presented and phases of learning are compared.

Table 1. Cognitive models of learning (phases) by Gagne et. al [7], Elliott et al. [10], Laakkonen [12] and Anderson & Finchman [1,2]

Gagne et al. [7]	Elliott et al. [10]	Laakkonen [12]	Anderson & Finchman [1,2]
reception (gaining attention)	transparency of operation		
expectancy (motivation, learning objectives)			
retrieval (recall of prior learninq)			Encoding

selective perception (apprentice, presenting the stimulus)	transparency of purpose	Information search	
sematic encoding/storage entry (acquisition, providing learning guidance)		Data collection	Planning
responding (eliciting performance)	accommodation	Knowledge management	Solving
reinforcement (providing feedback)		Knowledge form	
retrieval (assessing performance)		Knowledge build	
retention (memory storage)			
transfer (enhancing generalization)	accomplishment	Result of action	Response

In Elliott et al. [10] model the transparency of operations is directly related to the efficiency of a user interface that allows users to find, understand and then use rapidly and easily the functions of the user interface to complete a task or sub-task. In addition, transparency of operations refers to concept guessability used by Dix et al. [5], Bruijn et al. [3]. They define guessability as an indication of intuitiveness, i.e. how obvious the operations are that can be performed by users who have no experience with the device and have not received any earlier instructions. Bruijn et al. [3] use the term guessability as synonym for learnability.

Transparency of purpose means that users should be able to imagine the end product at any point during its use. However, it would be beneficial if transparency of purpose is understood and seen before the interaction process and not during it. The third phase of cognitive model of learning, accommodation is more related to the concept of easy-to-use than it is to easy-to-learn. The forth phase is very close to the concept of usefulness, which is separate concept from that of learning.

What are the differences and similarities between Anderson & Fitchman (2013) structure of thoughts and Laakkonen [12] theoretical model of learnability? The cognitive model of learning is non-linear and learning dynamics occur inside the six phases. The dynamic means that in every phases of learning has their own dynamics. For instance in information search phase user is moving towards and away from the right solution i.e. the process is not linear it is circulated and iterative. In addition, the six phases do no follow any given path.

Information search and data collection phases by Laakkonen

[12] can be related to Anderson & Fitchman (2013) encoding phase. Knowledge management is related to Anderson & Fitchman (2013) planning phase; however planning phase occurs already before the new artifact are taken in use. Knowledge form and knowledge build phases are related solving phase and result of action refers to Anderson & Fitchman's model's response phase.
In addition, it needs to be emphasis that knowledge management phase [12] needs to be investigate more detailed, because in that phase new knowledge is implemented to internal patterns "buffers" of human mind. Knowledge form and knowledge build phases are related to productions system and result of action refers to "change the style of system i.e. change the human behavior model. (see Anderson & Fitchman [1,2] and Laakkonen [12]

At the end, the theory by Fitts & Postner [8] emphasizes that a user has to "know what" before "know how" when interacting with the user interface. In addition, the assumptions of human towards a program are very close to Gagne's motivation (expectancy) phase of learning [10].

CONCLUSIONS

The information technology key research areas such as: digital health technologies, artificial intelligent, big data, internet of things, block chains, autonomous driving, robotics, augmented reality, identification technologies, cybersecurity are affecting human thinking, behavior and habits in their daily lives.
Understanding human thinking is crucial if we want to, create technologies, which correspond and satisfies the human needs. It is not only question of passive adaptation of human beings; it is question of human beings accommodation and assimilation in modern information society.

How can human behavior and thinking models be more deeply understood? We should study more detailed: a) human being primitive behavioral models (instincts, autonomous behavior, habits), b) deep emotions (falling in love, fear, betray, abuse), c) collect empirical research data from different user groups, artifacts, environments and task settings (train, metro, airport, hospital, home, work place, shop etc.) d) investigate organizational behavior and e) create new research methods (creative art methods). Nevertheless, it needs to be remembered that due to cultural differences, humans' backgrounds, perspectives and motivations, humans' interpretation of the wicked problem varies greatly case by case. (Pavie & earthy 2014, 5).

The rational and emotional minds are not separate units. Therefore, we also need to study instincts and deep emotions of human being.The rational cognitive thinking models cannot purely explain by human behavioral and habits. We need to be able to better understand human being primitive behavioral models (instincts). The primitive behavioral models are not distinguished. For instance intuitiveness could be explained more detailed if we could understand what part of our behavioral is based on instincts. The Card et al. [4] used the concept information scent in this context. As animals rely on scents to indicate the chances of finding prey in current area and guide them to other promising patches, so do humans rely on various cues in the information environment to get similar answers. Human users estimate how much useful information they are likely to get on a given path, and after seeking information compare the actual outcome with their predictions. When the information scent stops getting stronger (i.e., when human no longer expect to find useful additional information), the humans move to a different information source. Maybe investigating animal behavioral model we could understand the human primitive behavioral models and we could create more convenient products and services, which respond our needs.

At the moment, the methodical development of human thought and action research has focused in neuroscience. Beside of that we need to create new research methods. The creative art and agile design thinking methods has not been implied to rational cognitive research settings before.

At the end, research problems are becoming more complex and more holistic view of different research disciplines are needed. The technological, neuropsychological, HCl-research and cognitive communities of sciences presents different models of cognitive thinking. Similarities and differences has been identified in this paper.

The futurologists has focused to extrapolate present political, economic, society and environmental trends on attempting to predict future trends. During the recent years, the discipline has put more and more focus on the examination of social systems and wicked problems to be able to draw the future scenarios. Maybe futurologist could also help cognitive science to predict and form more holistic picture of human thought and action.

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