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A RELATIONSHIP BETWEEN COGNITIVE INFORMATION PROCESSING IN LEARNING THEORY AND MACHINE LEARNING TECHNIQUES IN COGNITIVE RADIOS

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Abstract. *The relationship between cognitivism as learning theory in education and machine learning is characterized in this survey paper. The cognitivism describes how learning occurs through internal processing of information and thus leads to understanding and retention. Cognitive information processing plays an active role to understand and process information that learner receives and relates it to already known and stored within learner's memory. Thus, the cognitive approach defines learning as a change in knowledge which is stored in learner's memory, and not a change in learner's behaviour. In regard with importance of various learning problems to designing cognitive communications systems the two main classification categories of learning techniques are explained. Furthermore, the cognitive radio learning algorithms that have been proposed are described. Finally, the similarities and differences among the principles of learning theories and machine learning are discussed.*
Keywords: *Cognitive Information Processing, Cognitive Radio, Cognitive Radio Learning Algorithms, Cognitivism, Learning Theory, Machine Learning.*

Introduction

One of the most indispensable components of a human and artificial intelligence is the ability to learn. As the paper intend to characterize a relationship between Cognitive Information Processing in Learning Theory and Machine Learning Techniques in Cognitive Radios, one need to have a definition of intelligence and learning. There are several definitions of these terms that have been proposed in the past. For the purposes of this paper, the terms learning, human intelligence and artificial intelligence will first be defined.

Learning is the process of acquiring new or modifying existing knowledge, behaviours, skills, values, or preferences (Gross, 2015). This definition shows the general characteristics of the learning process and can be applied to both human

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and machines. The term "Machine Learning" is defined first by Arthur Samuel, an American pioneer in the field of computer gaming and artificial intelligence, in 1959. Machine learning is a field of computer science that gives computers the ability to learn without being explicitly programmed (Samuel, 1959).

Human intelligence is the intellectual prowess of humans, which is marked by complex cognitive feats and high levels of motivation and self-awareness (Tirri & Nokelainen, 2012). Through their intelligence, humans possess the cognitive abilities to learn, understand, reason, form concepts and ideas, plan, solve problems, make decisions, retain information, and use language to communicate.

Artificial intelligence or machine intelligence is a possession of intelligence by machines. In computer science artificial intelligence is defined as the study of intelligent agents, which is any device that perceives its environment and takes actions that maximize its chance of success at some goal (Poole et al., 1998).

The cognitivism as learning theory describes how learning occurs through internal processing of information and thus leads to understanding and retention. Cognitive information processing plays an active role to understand and process information that learner receives and relates it to already known and stored within learner's memory.

To understand the relationship between cognitivism and machine learning, in section two, the principles of three main learning theories how human acquire, retain, and recall knowledge are explained. Next, the machine learning techniques in cognitive radio are examined in section three. Finally, the similarities and differences among the principles of learning theories and machine learning are discussed in the conclusion.

Cognitive Information Processing as Learning Theory

The most comprehensive theory about the nature and development of human intelligence during the 20th century is a Piaget's theory of cognitive development (Ginsburg & Opper, 1988). As a biologist, Piaget was interested in human intelligence, i.e. how an organism adapts to its environment. According to his theory, behaviour (adaptation to the environment) is controlled through mental organizations called schemes. Individual uses these schemes to represent the world environment and to select an appropriate action. This adaptation is driven by a biological drive to obtain balance between schemes and the environment (called equilibration).

Piaget hypothesized that infants are born with schema operating at birth that he called "reflexes." In other animals, these reflexes control behaviour throughout life. However, in human beings as the infant uses these reflexes to adapt to the environment, these reflexes are quickly replaced with constructed schema. Piaget described two processes, assimilation and accommodation, used by the individual though is life as he increasingly adapts to the environment. Jean Piaget also is a founder of Constructivism, which is the theory of knowledge that argues that humans generate knowledge and meaning from an interaction between their experiences and their ideas.

To understand how learning occurs one must know learning theories that are an organized set of principles explaining how individuals acquire, retain, and recall knowledge. Three are the learning theories: Behaviourism, Cognitive Information Processing (Cognitivism) and Constructivism (Figure 1).

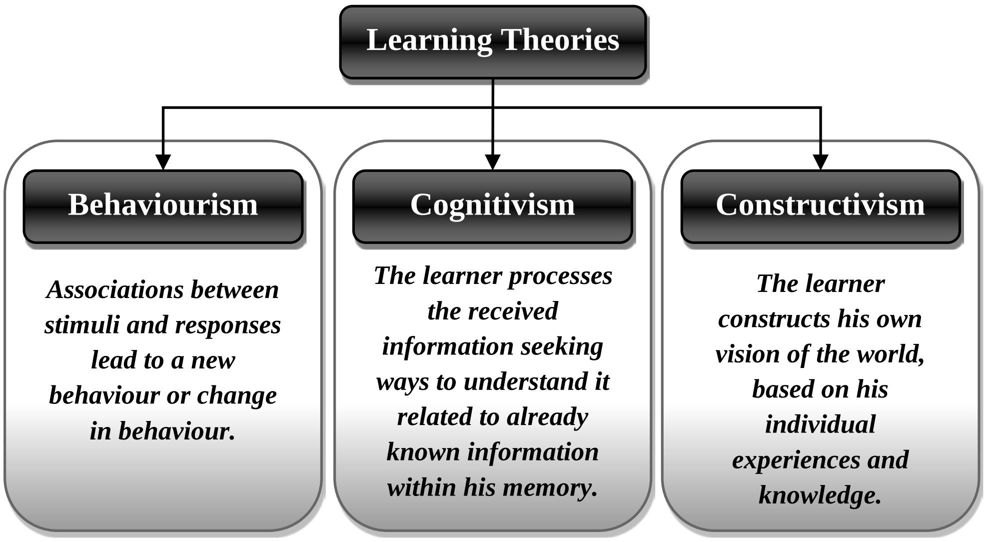

Figure 1. **Behaviourism, Cognitivism and Constructivism as Learning Theories**

Behaviourism defines learning as the acquisition of a new behaviour or change in behaviour. According to the behaviour theory the learning process begins with some stimulus from the environment and then the learner reacts with some type of response. The responses are so arranged to follow the desired behaviour. The new behavioural can be repeated so it becomes automatic. Thus, associations between stimuli and responses lead to a change in behaviour.

Unfortunately, behaviourism does not learn for creative thinking or problem solving. The students only recall some basic facts, automatic responses or performing tasks and do not take the initiative to change or improve things. Some examples of behaviourist learning theory are rote work, repetitive practice, participation or bonus points, verbal reinforcement, and so on.

Cognitive information processing is based on the idea that learner processes the received information, rather than simply responds to stimuli. Thus, the changes in behaviour are observed, but only when the learner plays an active role in seeking ways to understand received information related to already known and stored information within his memory.

Some examples of cognitive learning theory applications are classifying information, associating new content with something known, providing structure in efficient and meaningful ways, discussions, problem solving, analogies, imagery, mnemonics, and so on. As one can see, cognitive learning involves some reorganization of knowledge and experience, either by achieving new ones or changing old ones. Thus, cognitive learning is a change in knowledge stored in memory and not just a change in behaviour.

Constructivism is based on the fact that learner constructs his own vision of the world, based on his individual experiences and knowledge. Since the learning process depends on how the individual interprets the meaning of his perceptions, experiences and knowledge, the learning is unique and different for each person. Thus according to constructivist theorists, the learning is a process where individuals construct new ideas or concepts based on their prior knowledge and/or experience.

According to constructivism theorists the learning is a process of adjusting the learner's mental models to provide his new experiences. Because the learner needs a significant amount of knowledge to interpret and create new ideas, the constructivism focuses on preparing students to problem solve. Thus, the outcomes from constructivism are not always predictable because every learner has their own knowledge. Some examples and applications of constructivism are research projects, problem based learning, case studies, collaborative learning and group working, discovery learning, simulations, and so on.

Machine Learning in Cognitive Radios

A cognitive radio is a key technology that allows cognitive wireless devices to dynamically access the available spectral opportunities. The term Cognitive Radio (CR) was introduced by Joe Mitola in 1999 (Mitola & Maguire, 1999) and his PhD thesis (Mitola, 2000). The term CR was intended to describe "a goal-driven framework in which the radio autonomously observes the radio environment, infers context, assesses alternatives, generates plans, supervises multimedia services, and learns from its mistakes." In this way it could be interpreted as "a radio is a particular extension of software radio that employs model-based reasoning about users, multimedia content, and communications context" (Mitola, 2001). Thus, the CR is an intelligent radio or system that senses radiofrequency RF and microwave environment and can dynamically and autonomously adjust its operating parameters making decisions using gathered information, and can also learn and plan according to their past experience. Such a level of intelligence requires the CR to be self-, content- and context-aware.

Due to the complexity of CR technology, the FCC generalizes the CR definition to be "a radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets" (FCC, 2005). According to this definition, a cognitive radio has two key features, cognition capability and reconfiguration capability, which distinguishes it from traditional radio. These key features of CR are presented at Figure 2. The functional architecture of a cognitive radio illustrates how CR interacts with the radio environment continually while running cognition cycle to observe spectral opportunities, analyze them and decide the best actions to create plans to adapt itself for the best opportunities.

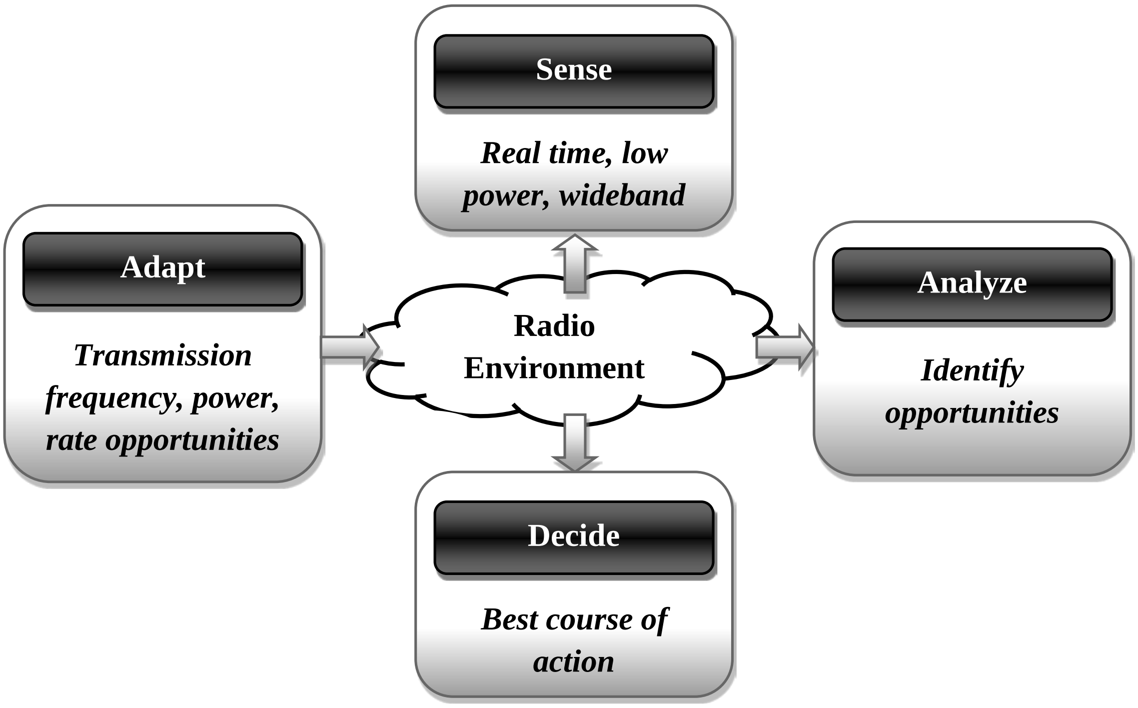

Figure 2. **Functional architecture of a cognitive radio (Khattab et al., 2012)**

Nowadays the CR capabilities are much more complicated and involve advanced technologies ranging from nanoscale electronic devices for system hardware development to artificial intelligence techniques for decision-making algorithms. In this context the term CR identifies the point at which wireless devices and the related software defined networks are sufficiently computationally intelligent about radio resources and related communications to detect user communications needs and to provide available radio resources and wireless services most appropriate to those needs.

As a result, the development of a cognitive radio system uses structured computational models of services and radio protocols to control the delivery of desired wireless services. The computational models include reinforced hierarchical sequences, which organize internal representation of CR, its user, and its environment, and the cognition cycle (see Figure 2). The structures supporting a cognition cycle are Observe, Orient, Plan, Decide, and Act phases.

The outside world generates stimuli. Cognitive radio analyses these stimuli to recognize the context of communications tasks. Input and output multimedia content is parsed for the contextual metrics needed to infer the context of communications (for example, urgency of the communication). The Orient-stage decides on the urgency of the communications in part from these metrics in order to reduce the delay of the user. Generally, the planning phase generates and evaluates alternatives, including expressing peer or network plans to get advice. The Decide stage allocates computational and radio resources to subordinate conventional radio software. The Act-stage initiates tasks with specified resources over a certain period of time (Mitola, 2000).

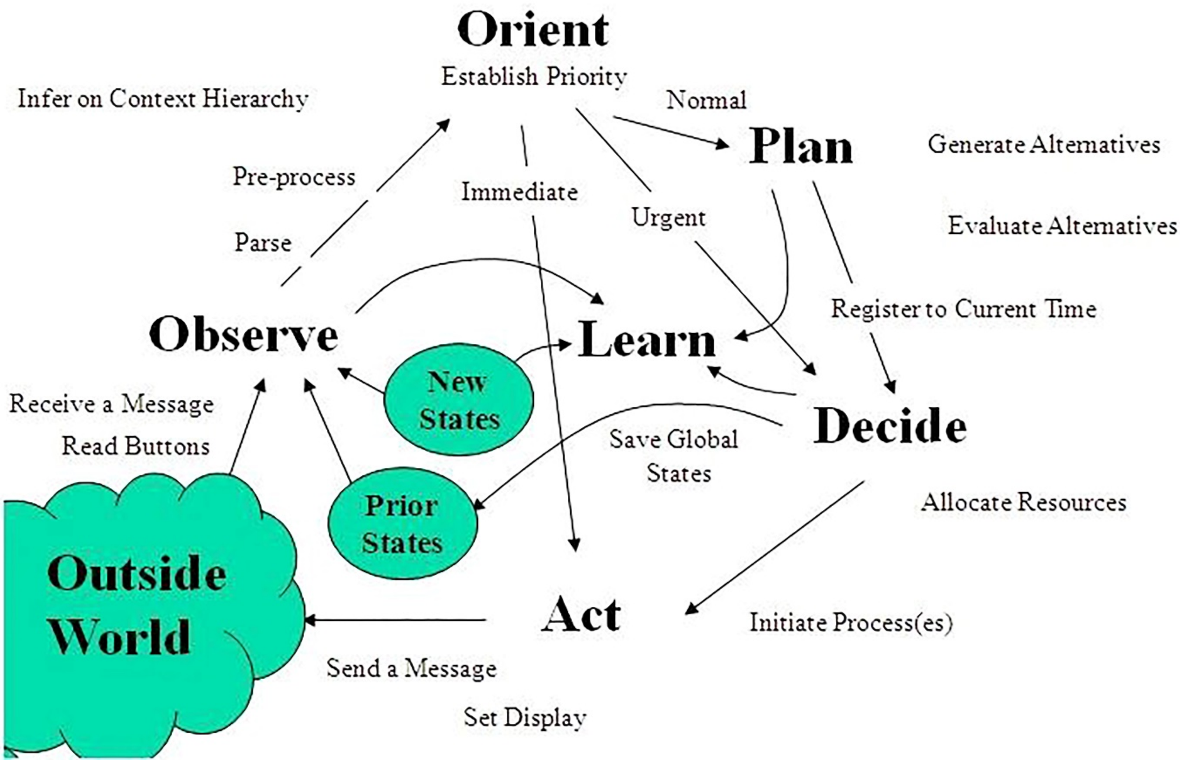

Figure 3. **Simplified Cognition Cycle (Mitola, 2000)**

Machine learning is integrated throughout the CR architecture. Three types of learning are supported by the cognitive behaviour model of cognitive radio: incremental, batch and supervised learning, which are related to three modes of behaviour: waking, sleeping, and praying, respectively.

The waking behaviour is optimized for real-time interaction with the user, isochronous control of software radio assets, and real-time sensing of the environment. Thus, the awake-state cognition maps environment interactions to the current stimulus-response cases, and incremental machine learning maps these interactions to integrated knowledge.

Cognitive devices detect conditions that permit or require sleep and dreaming. Sleep is intentional inactivity. Dreaming behaviour employs energy to retrospectively process experience from the waking behaviour using non-incremental machine-learning algorithms. These algorithms map current cases and integrated knowledge onto integrated knowledge. A conflict is a context where the user overrode a decision about which the device had little or no certainty. If the conflict can't be resolved, it will be placed in the list of unresolved conflicts.

The prayer behaviour attempts to resolve unresolved conflicts via the mediation of the CR device. Successful resolution maps network responses to integrated knowledge. Alternatively, the CR device may present the conflict sequence to the user, requesting the user's advice during the wake cycle.

After initial training, CR has a capability to be further trained either by the user or by the network. In addition, CR may be initialized to a previously learned starting point, which consists of sets of internal structured models.

For the radio channel, the vector of the energy levels estimated at cognitive radio devices is treated as a feature vector and fed into a classifier to decide whether the channel is available or not available.

Artificial intelligence may be represented to the following learning techniques: fuzzy logic, genetic algorithms, neural networks, game theory, reinforcement learning, support vector machine, case-based reasoning, decision tree, entropy, Bayesian, Markov model, multi-agent systems, and artificial bee colony algorithm (Abbas et al., 2015), (Bkassiny et al., 2013).

A classification algorithm can be categorized as unsupervised and supervised machine learning. The main difference between supervised and unsupervised algorithms is that each training energy vector is labeled with the corresponding channel. As unsupervised are known K-means clustering and Gaussian mixture model (GMM). The K-nearest neighbor (KNN) and support vector machine (SVM) are known as supervised.

The unsupervised K-means clustering algorithm partitions a set of the training energy vectors into K disjoint clusters. Each cluster is mapped to either the channel available or the channel unavailable class.

In the unsupervised Gaussian mixture model we obtain a Gaussian distribution from training vectors to a cluster. A GMM is a weighted sum of multivariable Gaussian probability densities. The parameters in GMM can be estimated by using the maximum likelihood estimation given the set of the training energy vectors.

The support vector machine (SVM) tries to find a linearly separable hyperlane with the help of energy vectors that lie closest to the decision line by maximizing the margin of the classifier while minimizing the sum of errors. In the SVM a set of training vectors which specify the decision function are obtained by maximizing the margin between separating hyperlanes and featured vectors.

The K-nearest neighbor (KNN) classification technique is a weighted technique based on the majority voting of neighbors. For a given test energy vector, the KNN classifier finds K neighboring training energy vectors among vector based on a particular distance measure. The distance can be calculated in different ways (Thilina et al., 2013).

It is possible for the CR devices to cooperate in order to achieve higher sensing reliability. As one can see the functional architecture of a cognitive radio and its cognition cycle are biologically inspired, based on neural-network-like nodes that respond to external stimuli and that process the resulting internal data structures.

Conclusion

As shown in Section three, the cognitive radio follows the cognition cycle for best resource management and network performance. It starts by sensing the environment, analyzing the outdoor parameters, and then making decisions for dynamic resource allocation and management to improve the utilization of the radio electromagnetic spectrum.

The human learning process is a process of committing the symbolic representations to memory where they may be processed. Thus, the study of learning is primarily approach through the study of memory. The information processing when human learn involves three stages: Encoding, when human collecting and representing information by sensations or observations; Storage, which is holding information in short-term memory for one to three seconds or in long-term memory; and Retrieval which is obtaining the learned information by human when needed. There are three categories of long-term memory. Semantic Memory is for verbal information or meaning. Episodic Memory is for events and for information related to a particular places and times. Procedural Memory is for how to do things. It takes a longer procedure to learn, but once the knowledge is learned, it will be remembered for a long time (Huitt, 2003).

The comparison of two learning processes in Cognitive Radio and Human are shown in figure 4.

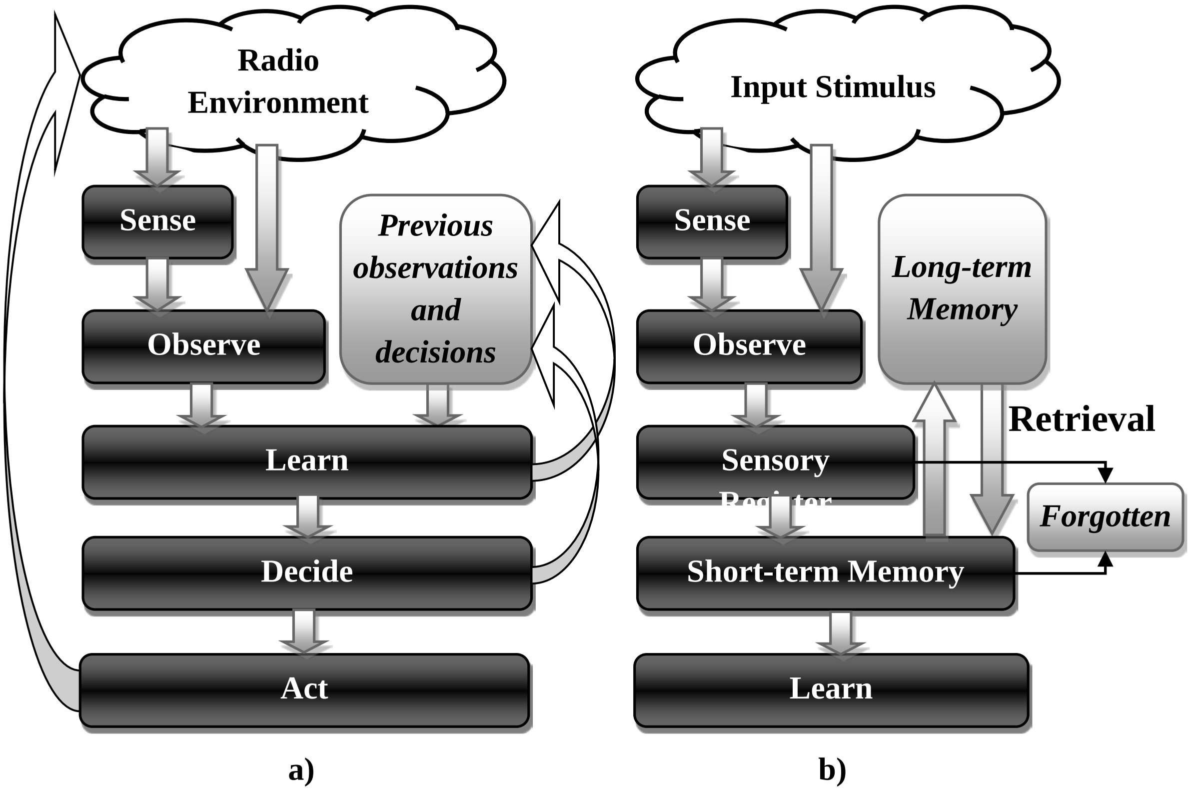

Figure 4. **The Learning Process in Cognitive Radio (a) and Human (b)**

As one can see the two learning processes are very similar because:

1. The learning process is the most indispensable component of a human intelligence and cognitive radio as artificial intelligence system. In both systems the learning is a process of creation knowledge from information, i.e., both systems can classify, organize, abstract, and generalize information obtained from the sensing.
2. Human as biological system and CR as technical system also can perceive and reason, i.e. they are able to obtain information about its environment and its own state, and they can use its knowledge for achieving its goals.

Unfortunately, it is a possibility for people to forget some information, which is the main difference between humans and CR systems.

Consequently, we can conclude that the learning is at the core of any intelligent system including human as biological system and CR as artificial intelligence system. The knowledge is used to achieve certain goals both in humans and in cognitive radio.

Finally, the principles of learning theories, behaviourism, cognitivism and constructivism, can be used as guidelines to select tools, techniques and strategies that promote learning in education. When teacher decides which strategies to use, it is important to consider the level of knowledge of the students, the its thought processing demands, and the desired outcomes like generation of new ideas or a only a single answer.

References

Abbas, N., Nasser, Y., & El Ahmad, K. (2015). Recent advances on artificial intelligence and learning techniques in cognitive radio networks. *EURASIP Journal on Wireless Communications and Networking*, *2015 (1)*, 174.

Bkassiny, M., Li, Y., & Jayaweera, S. K. (2013). A survey on machine-learning techniques in cognitive radios. *IEEE Communications Surveys & Tutorials*, *15* (3), 1136-1159.

Federal Communications Comission (FCC) (2005). ET Docket No 03-108: Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies.

Ginsburg, H. P., & Opper, S. (1988). *Piaget's theory of intellectual development*. Prentice-Hall, Inc.

Gross, R. (2015). *Psychology: The science of mind and behaviour 7th edition*. Hodder Education.

Huitt, W. (2003). The information processing approach to cognition. *Educational psychology interactive*, *3* (2), 53-67.

Khattab, A., Perkins, D., & Bayoumi, M. (2012). *Cognitive radio networks: from theory to practice*. Springer Science & Business Media.

Mitola Iii, J. (2001). Cognitive radio for flexible mobile multimedia communications. *Mobile Networks and Applications*, *6* (5), 435-441.

Mitola, J. (2000). Cognitive radio---an integrated agent architecture for software defined radio.

Mitola, J., & Maguire, G. Q. (1999). Cognitive radio: making software radios more personal. *IEEE personal communications*, *6* (4), 13-18.

Poole, D., Mackworth, A., & Goebel, R. (1998). Computational intelligence: a logical approach.

Samuel, A. L. (1959). Some studies in machine learning using the game of checkers. *IBM Journal of research and development*, *3* (3), 210-229.

Thilina, K. M., Choi, K. W., Saquib, N., & Hossain, E. (2013). Machine learning techniques for cooperative spectrum sensing in cognitive radio networks. *IEEE Journal on selected areas in communications*, *31* (11), 2209-2221.

Tirri, K., & Nokelainen, P. (2012). *Measuring multiple intelligences and moral sensitivities in education, Vol. 5*. Springer Science & Business Media.