MENTAL MODELS – THEIR DIAGNOSIS AND ROLE IN KNOWLEDGE ACQUISITION

Mental models play an important part in the process of knowledge acquisition. Knowledge acquisition through creation of a mental model is immanently active, attained through interaction with the environment. While basing on personal experience acquired in the learning process, a student becomes the central reference point to internalized information. The natural manner of acquiring knowledge through mental models differs significantly from typical teaching practices in educational curriculum. Knowledge at school is acquired in a passive manner – the student is not an active player, but merely a recipient of highly abstract content. The article presents the review of existing literature on various types of knowledge representation with special emphasis on diagnostic methods used to understand mental models and the concept of experience-based learning. Insight concerning how mental models develop and operate may significantly improve school teaching methods, especially in abstract disciplines such as mathematics.

Key words: mental models, diagnosis; school education; knowledge acquisition

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Mental models are cognitive tools used to represent the surrounding reality (Gentner, 2002). They are theories of mind about how things operate in the physical world - both the concrete facts: what causes plants to grow, or on what factors it depends how far a thrown object will fly, and more abstract notions, such as electric current, linear function or gravity. Through the use of mental models, people make sense of their experiences and combine them into a global picture of the surrounding world, which allows them to perceive causal links between events, conduct deductive and inductive reasoning, and formulate expectations about the dynamics of observed phenomena (Gentner and Stevens, 1983; Johnson-Laird, 1983). Thus, mental models allow for goal-directed action in the environment.

Mental models are interesting for developmental psychologists and educationalists because they play a central role in the acquisition of knowledge. They allow to perform...
so-called “Gedanken experiments”, i.e. mental simulations of future states of the system, once initial conditions are determined (Hegarty and Just, 1993; Gentner, 2002; Markman & Gentner, 2001, Rasmussen, 1983; Rouse and Morris, 1986). Formation of a mental model of a given knowledge area allows for drawing conclusions from premises and using these conclusions to cope with new problem situations (Jonassen, Wilson, Wang & Grabinger, 1993; Norman, 2002).

Learning through creation of a mental model takes place in a dynamic relationship between the individual and her environment – it is situated and motivated by the need to achieve outcomes beneficial for the subject (Choi & Hannafin, 1995). Knowledge about the construction of mental models can aid teachers to manage the learning process so that students are able to produce situation-driven, subject-centered models of the world that stimulate active and rational behavior in the environment.

It is not a simple task to describe the content of a mental model of a given individual - often its operation and way of representing knowledge is a mystery even for the owner himself. As stated by Rapp (2005), mental models do not exist physically, they cannot be accessed by neuroimaging or surgery, and introspective interview can reveal only that part of the mental model that is accessible from the meta-cognitive level. On the other hand, understanding the construction of mental models is a necessary condition for distinguishing ineffective from effective models and learning how to promote the acquisition of the correct ones. It is particularly important in abstract fields such as mathematics, where the concepts under study do not have real-world equivalents, which makes it difficult for students to spontaneously produce accurate mental models. In the following paragraphs we will review literature on how mental models can be measured and quantified. We will also focus on how the knowledge of the construction and operation of mental models can help develop effective strategies for teaching mental models in the school environment.

DEFINITION OF MENTAL MODELS

The founder of the concept of mental models, Scottish psychologist and sociologist Kenneth Craik described them as “small-scale models” of reality used to “anticipate events, to reason, and to underlie explanation” (cit. after Johnson-Laird, Girotto & Legrenzi, 1998). Although they are a purely theoretical construct, “existing” only in the mind, it is difficult to explain diverse aspects of human functioning without referring to mental models (Conant & Ashby, 1970).

The defining feature of the concept of a mental model is that it is not merely a replica of the real-world experience, but that it allows to go beyond the observable facts (Shute & Zapata-Rivera, 2008). Kahneman & Tversky (1982) use the computer metaphor to explain the working of a mental model. In the same way that a computer program can be “run” to “return” specific results of procedures and functions, the mental model can be “put into motion”, which results in the formation of inferences about the future state of the world.

Mental models reflect the process of acquiring knowledge through experience - through accidental observations, erroneous conclusions, and omissions of important facts. Norman (1983) summarizes conclusions from own experimental work on mental models by stating that mental models are often incomplete, messy, unscientific, and inaccurate. Often, people prefer to put more physical effort in working out the problem than to develop an adequate mental model to plan their actions. Oftentimes their inference is based on superstitions and magical
thinking, and inaccurate models, if assimilated well, are not easily changed, even in the face of the facts that deny them.

The process of reasoning is precise, provided that the underlying mental model accurately maps relations existing in the real world. Even if the line of reasoning as such is correct, if it is based on false assumptions, it will lead to wrong conclusions. As confirmed by research, having an adequate model determines more effective acquisition of knowledge in many areas (e.g., Mayer, 1989; DeKleer & Brown, 1981), especially in sciences such as mathematics (Rouse & Morris, 1986). Comparisons between experts and laymen have demonstrated that expert mental models do not include more information, but they more complex and accurate in representing the connections between relevant concepts (Chi et al. 1981; Glaser, 1984, cf. Fig. 1).

Unfortunately, “unlearning” wrong mental models is not a simple task. As reported by many authors (Clement, 1983; Collins & Gentner 1987; DiSessa, 1982; McCloskey, 1983), even targeted interventions aimed at changing an irrelevant model may lead to the person sustaining the amalgam of two models simultaneously – the old, well-assimilated model and the new, correct one – especially when daily experiences do not provide clear evidence of the validity of the new knowledge representation.

In the summary of mental models’ definitions we can conclude that they are internalized structures of knowledge used to solve problems. They can be put into motion in order to examine causal relationships between events and predict effects that are neither visible, nor obvious at first glance. They can be used in a variety of circumstances as a function integrating situational stimulation with the prior knowledge of the subject (Rapp, 2005). Whether the reasoning process leads to successful or unsuccessful outcomes depends on the design and the correct use of the model.

In the next sections we will look into main constituents of this knowledge representation system. We will examine various forms of information representation within mental models and review the methods used for their evaluation. Accurate diagnosis of a mental model is a necessary prerequisite for initiating the process of unlearning incorrect assumptions and developing a more adequate model of a concept under study.

**DIFFERENT SYSTEMS OF KNOWLEDGE REPRESENTATION WITHIN MENTAL MODELS AND THEIR EDUCATIONAL POTENTIAL**

The notion of a mental model is comprehensive, and yet difficult to operationalize (Jonassen, Strobel and Gottdenker, 2005). There is no clarity as to whether the models are semantic in nature, whether they are mental simulations or procedural knowledge recorded in the form of inference rules. Researchers generally
agree that mental models consist of many heterogeneous but overlapping knowledge representations (Johnson-Laird, 1983). They are constructed in verbal code, that allows for understanding explanations provided by other people and formulating a semantic description of a phenomenon, but they also consist in non-verbal, imagery representations of objects previously encountered in real life (Johnson-Laird, 1983; Markmann & Gentner, 2001). As stated by Rapp (2005) they preserve “spatial, physical, and conceptual features of real experiences” used to “generate hypotheses, solve problems, and transfer knowledge to new domains” (p.45). Jonassen et al (2005) systematically enumerate different types of knowledge representation that comprise mental models. In the following sections we will base upon these authors' division of types of knowledge representations within mental models, while discussing various methods used to diagnose and measure their educational value.

**STRUCTURAL KNOWLEDGE**

The underlying component of the mental models are organized structures of semantic knowledge: concepts, rules and relations between them (Jonassen et al., 2005). The relationships between concepts are considered to be qualitative rather than quantitative (Forbus, 1984, Forbus & Gentner, 1997; Gentner, 2002; Shute & Zapata-Rivera, 2008). This means that they are based upon rough estimations of whether one value is larger or smaller than the other. The qualitative process theory (Forbus, 1984) defines the following components of the mental model structure (as in the water-boiling model example): a) units, such as water in a pot; b) qualitative relations, such as water temperature (above freezing and below boiling point); (c) processes that cause change in the system (e.g. heat supply) (Gentner, 2002).

Structural relationships can be reflected and measured with so-called concept maps (Shute & Zapata-Rivera, 2008), where the connections represent a variety of semantic dependencies between the concepts in the mental model (c.f. Fig. 2). The concept map is the externalization of the semantic knowledge contained in a mental model. It is a kind of a “map of thought”, a visualization of connections between concepts, created by the subject with help of an interviewer. In a typical concept map, notions are interconnected by arrows representing a given type of relationship, such as “is a part”, “causes” and “contributes to” (Shute & Zapata-Rivera, 2008). The direction of the arrow reflects the direction of reasoning.

![Figure 2. Examples of concept maps, after: a) Gentner (2002), b) Shute & Zapata-Rivera (2008).](image)

Concept maps provide a good measure of the complexity of mental models. Its indicators are, among others, number of nodes representing notions, number of connections between them, number of crosswise connections, number of hierarchical levels or number
of examples of a given phenomenon (Vo, Poole & Courtney, 2005; Shute & Zapata-Rivera, 2008). The common practice is to compare the concept maps developed by laymen with maps produced by experts (Ifenthaler, Pirnay-Dummer & Seel, 2007).

The advantage of this method of diagnosing mental models from the perspective of teachers is its simplicity and applicability in the classroom context. Because concept maps are based on the declarative knowledge, student can build their own conceptual maps in interaction with the teacher, who simultaneously identifies possible shortcomings and contradictions in the mental model and proposes improvements.

PROCEDURAL KNOWLEDGE

Another constituent of mental models according to Johanssen et al. (2005) is procedural knowledge. It allows the subject to use a mental model in relation to the physical world. The result of the working of the procedural aspect of a mental model is a plan of actions leading to possibly best solution to a problem. In the boiling water example, the procedural knowledge allows the subject to select the right pot, appropriate gas jet, and estimate the water cooking time.

Procedural knowledge can be diagnosed by asking the subjects to think aloud during the task solving process (think-aloud protocols, Jonassen & Henning, 1999; Ericksson & Simon 1984). Another popular method is the teach-back procedure where subjects are asked to explain a layman how to perform a task or how to use a certain tool (van der Veer, 1989, Jonassen et al., 2005). However, verbal account of the reasoning process is not sufficient because it gives access only to the conscious layer of the model’s operation. Therefore many researchers choose to investigate procedural knowledge in action, by selecting tasks that differ in various details in order to determine which mental model has been used to solve the task. These details refer to variables such as patterns of correct and incorrect responses, reaction times, ocular movements, or typical errors made by the subjects (Gentner & Gentner 1983; Hegarty & Just 1993; Gentner, 2002). The strategies used by a subject allow for the assessment of the level and complexity of a mental model.

The development of procedural knowledge in the school environment can supported by all kinds of experiments in the physical world, manual exercises, or self-execution projects. In chemistry class, such tasks may require building a molecular model of a chemical compound, or preparation of a solution, in geometry – assembling a geometric structure, in biology – work with the microscope. The methodology proposed here is well known to teachers, but still too rarely used. In the digital age, procedural knowledge can gain additional support through the use of specially designed computer programs. A great example of the program for interactive fun during assimilating abstract mathematical concepts is Geogebra (geogebra.org). Similar free-access programs available on the Internet can be counted in thousands.

VISUAL IMAGERY

A relevant component of mental models is imagery, i.e. mental images of a represented system (Jonassen et al. 2005). In his picture theory of language, Ludwig Wittgenstein (1922) defines thought as logical picture of facts. Many people acquire knowledge by constructing a mental image of a system that may resemble a diagram or architectural schema, but may also include perceptual memories of the subject (in the example of water: the mental image of a stove and cabinet with pots). Ability to imagine a building from the other side, skill of reading maps,
appropriate assessment of distance between places in space and events in time, abstract concepts of numbers, volume or weight - all these are examples of mental models describing perceptual-spatial relationships.

The concept of functional isomorphism (Shepard & Cooper, 1982) is essential to understand the role of mental imagery in knowledge representation. It states that transformations made on mental images represent real manipulations made on objects in three-dimensional space (they are analogs of real transformations). The mind represents these transformations together with the spatial arrangement of the elements of an object. One can talk about enlarging, rotating, folding, moving, replaying etc. of mental models. Shepard and co-workers have experimentally demonstrated that changes in visual images of objects are similar to those that can be observed in objects in real life.

The ability to create spatial representations is measured by a variety of paper and pencil tests. There are three main special abilities: mental rotation, spatial perception and spatial visualization (cf. Turos & Ervin, 1999). Mental rotation is defined as the ability to rotate imaginary representations of two-dimensional and three-dimensional objects. One of the most common tests of mental rotation is the MRT (Mental Rotation Test) developed by Vandenberg and Kuse (1978), and it also measured by the APIS-Z subscale (Matczak, Jaworowska, Szustrowa & Ciechanowicz, 1995). Spatial perception is the ability to ignore distractors hampering the recognition of spatial relationships and identification of a perceived object. The tests used to measure special perception are Rod and Frame test (Witkin, Dyk, Faterson, Goodenough & Karp, 1962) or Water Level Test (Piaget & Inhelder, 1948/1956). Spatial visualization is defined as the ability to develop an appropriate, multi-stage solution to a problem while complex spatial information. This capability is measured by Embedded Figures and Paper Folding test (Ekstrom, French, Herman & Dermen 1976).

Research shows that the visual-spatial imagery can not only be measured, but also trained. Positive impact of training consisting in multiple test solving and computer game playing, or of targeted school interventions on the level of spatial abilities was characterized in many studies (e.g. metaanalysis of Baenninger & Newcombe, 1989, Cherney, 2008, De Lisi & Wolford 2002, Voyer, Nolan & Voyer, 2000). Training may also play a role in minimizing gender differences observed in special skills (Voyer, Voyer & Bryden, 1995), or even in elimination of these differences (e.g. Cherney, Jagarlamudi, Lawrence & Shimabuku, 2003). As a consequence, women may gain broader access to typically ‘manly’ careers such as engineering, mathematics, physics, medicine, architecture, sports or aviation (Turos & Ervin 1999). Spatial skills and mental imagery should therefore be treated by educators as an ability that is subject to training and learning, and not as an innate feature of students.
METAPHORS

Metaphors are the most natural, spontaneous method of creating mental models (Jonassen & Henning, 1999; Jonassen et al., 2005). A metaphor can encapsulate meaning of a mental model because it combines many distinct elements: imaginary, symbolic, structural and referential – allowing for the formulation of analogies and comparisons to already learned domains (ibid, Gentner, 2002). Certain types of metaphors tend to be universal. For example, Gentner and Gentner (1983) identified two common models of electricity – the flowing water model and the moving crowd model. Although none of them is entirely correct, both are useful for explaining different class of phenomena related to electricity. The concept of voltage is easy to understand in the flowing water model whereas resistance is easier to predict within the moving crowd model (Gentner, 2002).

Measurement of metaphors within mental models can be conducted through interviews or questionnaires, it can also be tested in action similarly as in procedural knowledge (Collins & Gentner 1987, Kempton 1986). In a school setting, teacher’s suggestion of a right metaphor may allow students to intuitively capture the essence a phenomenon and relate it to notions from real-life contexts in the same way as in proverbs.

EXECUTIVE KNOWLEDGE

The next building block for mental models is executive knowledge (Jonassen et al., 2005). It determines flexibility of knowledge representation, i.e. whether a person is able to choose the adequate mental model for a specific problem situation. Activation of the right mental model allows for effective allocation of cognitive resources, which minimizes the cognitive effort put in the task. Measurement of this aspect may involve checking how quickly a person is able to switch from one cognitive strategy to another in the response to a gradual change in a problem situation (Jonassen et al., 2005). The student develops executive knowledge as a result of persistent repetitions of tasks and assignments, however equally important is the need to acquire many equivalent task-solving techniques. Equipped with many methods, a student can flexibly choose the effective strategy suitable for a specific problem situation and resources at hand.

BELIEFS

Beliefs can be defined as conscious or unconscious axioms that person uses to direct oneself in life (Jonassen et al., 2005). A belief represents the connection between the model and the person’s individuality (Durkheim, 1915, after Jonassen et al., 2005). Personal beliefs on ontology and epistemology lie at the foundation of a coherent personality, often being intrinsically incoherent. Thus, changing a particular belief system can result in a fundamental change in the way the person understands the world.

An example of how beliefs influence mental models is the concept of attribution. People who, when experienced failure, attribute it to permanent dispositions (abilities) rather than external factors, are less likely to invest more cognitive effort into improvement of their results and learning (Gutbezahl, 1995). Also personality traits such as dogmatism (Rokeach, 1954) or need for closure (Webster, Kruglanski, 1994) may determine the way in which information is processed, the choice of reasoning premises and the construction of mental models. The remedy against the creation of ineffective, undermining attribution in school education is the attitude of a teacher who praises the effort and progress of a student, not the final effect of her work (e.g. Dweck, 1986).
The review of the various components of mental models demonstrates how rich this knowledge representation is. The traditional way of presenting knowledge in school, if relying mainly on theoretical explanations and solving abstract tasks, is not enough to replace the multimodal naïve knowledge accumulated through interaction with objects in physical space. Learning through the creation of a mental model is not just about gaining comprehension, but also about everyday use of knowledge and its testing in the real-world environment.

Although people can learn by studying systems of concepts and theorems, the natural way to learn is learning through experience, which leads to the development of mental models. Understanding the natural, experiential and context-related mode of knowledge acquisition through mental models allows for such a selection of educational tools that would adjust for its advantages and shortcomings.

THE CONCEPT OF EXPERIENCE-BASED LEARNING

We have noted that mental models reflect the experience gained through interaction with phenomena in the physical space. The literature on mental models points out the conservative nature of human reasoning, in the sense that it is based on representations related to the context in which knowledge acquisition has taken place (Gentner, 1989; Medin & Ross, 1989). Consequently, it is often based on incomplete and inaccurate data, and does not take into account these aspects of a represented phenomenon, that were not be acquired through personal experience.

The experiential nature of knowledge is often ignored in school. Frequently, examination in disciplines such as physics or mathematics is based on tasks with a typical, uniform structure (Pollit & Ahmed, 2000). This results in students adopting one characteristic method of problem solving instead of building a more flexible, holistic representation of a given knowledge area. Subjected to such training, students learn to expect that they will be asked about something in a specific way. If only a given task type is changed, they cannot cope with the transfer of knowledge to the new context.

The lack of transfer has been linked to the way of teaching in school education, in which information is often abstracted, separated from the conditions in which it can become meaningful (Carraher, Carraher, & Schliemann, 1985; Lave, 1979; Perkins, 1985). Students learn to solve tasks within abstracted, often overly simplified, inauthentic contexts, often without access to everyday tools typically used in a given problem situation.

The important property that inhibits the process of acquiring school knowledge is sustainability of inaccurate mental models. Studies show that theory-driven training is not adequate to transform the naïve knowledge accumulated through experience (Clement, 1983; diSessa, 1982; McCloskey, 1983). In the standard, passive learning paradigm, students are merely passive recipients of knowledge, and the learning process is reduced to consumption of information provided by the teacher.

Criticism of decontextualized, teacher-centered, passive learning environments led to the establishment of new approaches in educational psychology that stress the importance of the active aspect of learning – so called learning-by-doing (e.g. Barron & Darling-Hammond, 2008; Jonassen, Cernusca & Ionas, 2007). These approaches include constructivism (Jonassen, 1991; or constructionism Papert, 1991), situated cognition (Choi & Hannafin, 1995) as well as the generative learning model (Wittrock, 1974). In order to acknowledge the reader with the experience-based learning concept, we will briefly discuss suggestions of the theories mentioned above.
CONSTRUCTIVISM

Since its inception in the 1990s, constructivist epistemology has significantly influenced the psychology of learning field (Jonassen et al, 2007). It does not mean, however, that it is approach has been from then on used in the classroom, in which the still dominating paradigm is the concept of knowledge as an objective and context-free set of rules and facts (Korthagen, Loughran & Russell, 2006). The constructivist perspective assumes that the mind generates its own “conceptual ecology” to interact with the environment and give meaning to the world. Thus, sense making is a process that emerges from action and from reflection on that action shared with other people (Jonassen, Hernandez-Serrano, & Choi, 2000). The student is a conscious, active and reflective subject responsible for building their personal mental models.

Constructivism as the philosophy of teaching proposes that the best teacher of a student is the student herself (Jonassen, 1991). Constructivists recommend creating such learning environments that would promote personal involvement of students and gaining practice by working on specific projects and real life problems. By solving authentic, complex problems, students acquire knowledge through self-guided action, by observing and testing the effects of their enterprises and by sharing their insights with the teacher and the group (Jonassen, Howland, Moore & Marra, 2004; Papert, 1991). The role of the teacher is rather to supervise the learning process than to transfer knowledge, as well as to inspire students and to give them the right to their own initiative.

Constructivist learning allows students for direct interaction with knowledge through usage of various educational aids such as visualizations, diagrams, computer programs, etc. The instructions of a constructivist teacher will provide students with metaphors that use familiar concepts, encourage testing knowledge in practice, and pertain to the beliefs of the students about the surrounding world. They utilize natural curiosity of students and encourage them to learn through discussing with peers, asking questions and finding answers.

THE GENERATIVE LEARNING MODEL

The theory of generative learning emphasizes the role of the student’s activeness in reorganizing and integrating new information. The student herself assigns meaning to new information by building associations between different elements of the learned material and the existing representation model in the mind (Fiorella & Mayer 2015; Wittrock 1974). Generative learning is thus the process of transforming the incoming information (e.g. words and images) into useful knowledge (e.g. mental models, schemas). School education can promote this way of learning by identifying different techniques for student’s self-development.

Examples of such techniques, which has been proven to be effective by scientific research, can be found in the paper by Fiorella & Mayer (2016). These are: preparing own summaries of the learned material (with means of both words and images, see: Leopold, Sumfleth & Leutner, 2013), building conceptual maps, drawing, imagining, teaching others, as well as self-explaining, self-testing, and enacting. According to the researchers, these strategies can facilitate building of accurate and permanent mental models.

SITUATED COGNITION

The theory of situated cognition emphasizes that learning cannot be separated from the
social, cultural and physical context in which it takes place (Bransford et al, 1992, Greeno, Moore & Smith, 1993). The learning process is understood in terms of increasing efficiency of student's performance, not in terms of knowledge accumulation. In an educational context aimed at supporting situational cognition, students receive support in the process of personal construction of meanings about the world they experience. The teacher is perceived more as a craftsman than an information-teller. Her role is not explaining the material, but the continuous and interactive facilitation of the learning process. The facilitation can take various forms such as: discussion, modeling, coaching, providing cognitive tools and consulting (Choi & Hannafin, 1995). Being in control of own learning process provides the student with self-regulation and self-correction skills, and also helps to build internal motivation and high self-esteem.

An important recommendation of this school to be used in a classroom is taking into the account the context-dependency of knowledge use. Students should be encouraged to take actions similar to those that they will undertake as adult practitioners and experts, i.e. to solve real-life problems (Barron & Darling-Hammond, 2008, Wilson, 1993). Change is also proposed in the approach to student assessment – it is recommended to focus on the ability to diagnose and manage cognitive growth rather than to evaluate student achievement. (Choi & Hannafin, 1995).

SUMMARY

Our literature review shows that effective teaching of accurate mental models should be based on the learning experience gained in or outside the classroom. It should take place in an environment, in which the student can actively test and validate the elements of the theory, by influencing events through own deliberate manipulation. Under such conditions, learning is the result of one's own actions in the environment, mistakes as well as correct decisions.

The concept of experience-based learning, accounting for the natural way of representing knowledge, may help teachers to make full use of the educational potential of an accurate mental model. Mental models are built of many parallel forms of knowledge representation systems, each of them easily diagnosed and modeled in the classroom. Educational intervention at each of these levels can result in student’s deeper processing of information and a better ability to use knowledge in practice.

REFERENCES


MODELE UMYSŁOWE – ICH DIAGNOZA I ROLA
W NABYWANIU WIEDZY

STRESZCZENIE

Modele umysłowe odgrywają ważną rolę w procesie nabywania wiedzy. Nauka poprzez wytworzenie modelu umysłowego jest w sposób immanentny aktywna, zdobywana w interakcji z otoczeniem. Opierając się na osobistym doświadczeniu, uczeń staje się centralnym punktem odniesienia dla przyswajanych informacji. Naturalny dla dziecka, oparty o budowanie modeli umysłowych sposób nabywania wiedzy, różni się od typowych zasad nauczania przyjętych w szkole. Wiedza szkolna podawana jest najczesniej w sposób pasywny, czyniąc dziecko obserwatorem, a nie aktorem, i biernym odbiorcą treści na wysokim poziomie abstrakcji. Artykuł stanowi przegląd istniejącej literatury ze szczególnym uwzględnieniem metod diagnozy różnych sposobów reprezentacji wiedzy w modelach umysłowych oraz koncepcji uczenia się opartego o doświadczenie. Wiedza na temat tego, jak tworzą się i działają modele umysłowe może poprawić skuteczność nauczania szkolnego, szczególnie w abstrakcyjnych dziedzinach wiedzy, takich jak matematyka.

Słowa kluczowe: modele umysłowe, diagnoza; edukacja szkolna; proces nabywania wiedzy.