

Creating and Using Symbolic Mental Structures Via Piaget's Constructivism and Popper's Three Worlds View with Falsifiability to Achieve Critical Thinking by Students in The Physical Sciences

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ABSTRACT

Learning a new concept requires the mind to enter into a state of disequilibrium and then progress through identified stages to re-establish eventually a new state of equilibrium. The human intellect persists in a dynamical equilibrium state while maintaining self-satisfaction and a contented worldview by constantly integrating and assimilating incoming information that resonates with its current understanding and previous experiences. This equilibrium state allows reflective thought and reassurance to the individual about what is already known albeit it with a limited generalization. However, with the onset of receiving and assimilating a new concept, you are thrown into a state of mental disequilibrium. It is the need to remove the disequilibrium that requires either critical thinking by the individual, resulting in an expanded worldview, or a discounting of it while maintaining a disengaging behavior. The former allows re-establishment of mental equilibrium with an expanded understanding, and the latter persists by never departing from equilibrium. In either case, the intellect has its equilibrium—one instance with requisite development of new understanding, the other without change. To restrict the onslaught of a constant barrage of new concepts, underprepared students avoid majoring in the physical sciences, opting instead to pursue other majors or to take fewer physical science courses. To address the lack of effective learning, we have developed the notion that individual Symbolic Mental Structures, as a key component of constructivism, can assist the underachieving student to become more engaged in the physical sciences and academia in general. This approach requires us to revisit Piaget's constructivism theory, Karl Popper theory with its falsifiability criterion, which supports the former, and to consider Bloom's affective and cognitive domains.

1. INTRODUCTION

Self-actuated learners in the physical sciences typically follow the path of constantly engaging new concepts to expand their worldviews, while the underdeveloped students do not do so, or at most, minimally [1-3]. What is the difference between these two students? How to get the second student to be more engaging relative to the first? In

this regard, we recognize under the constructivism theory that everyone "constructs" his or her own worldview, thus allowing one person with proper understanding and resources to acquire readily new knowledge. Likewise, under constructivism, if a person does not have the skills or wherewithal as needed to acquire easily new knowledge or new concepts, he or she avoids the effort to learn what is being taught. In opposition to accepting poor performance from underdeveloped students, we focus on how to help them acquire a key component missing in their approach to learning.

In this regard, the onset of learning begins with simply applying memorization, recording, valuing, comparing, and contrasting events or situations, all of which are represented in Bloom's affective domain or his cognitive domain. The self-actuated learner, without even knowing of these domains, develops a knack for critical thinking while other students languish in states of underperformance. Additionally, each individual, according to Piaget's constructivism theory, learns new concepts by constructing knowledge in the mind. To that extent, we have developed the notion of individual symbolic mental structure. These structures (or schemas) are in the form of mnemonics, acronyms, and a few other mental structures (mental patterns) of the mind that can assist students with engaging and retaining new concepts long enough to develop connections between them, current knowledge and previous experiences. Because of variations in shapes, we call these patterns "mental hooks," "mental straights," "mental S's," or "mental waves." All students, including the able-minded ones and struggling underdeveloped groups, can benefit from these patterns in the physical sciences.

We revisit, in this study, Jean Piaget's Constructivism theory on how the intellect receives, processes and assimilates new knowledge. Moreover, it is recognized that Karl Popper's Three Worlds View supports Piaget's theory by having an iterative process of asymptotically ascending to truth or reality. Important in Popper's theory is that of falsifiability, and the fact that it must be an integrated ingredient of any viable intellectual theory on learning. The falsifiability aspect of the theory ensures that external reality occurs, not just the subjective suppositions as developed internally by one's own intellect without the benefit of testing and measurement. Thus, acquired new knowledge must be measured and evaluated in comparison

to the outcomes of other individuals, who are also learning the same new concept. While each individual constructs his or her own mental structure of the problem, different participants should arrive at the same objective outcome.

This paper provides a rationale for using Piaget Constructivism theory in conjunction with Karl Popper Three Worlds theory, Bloom's Affective Domain and Bloom's Cognitive Domain and the notion of using schemas to receive and integrate new knowledge to assist in one's critical thinking. First, a presentation is given of Jean Piaget Constructivism, followed by a description of Karl Popper's Three Worlds View [4, 5]. Next a connection is made between the two theories, followed by statements of Bloom's affective and cognitive taxonomies and how they afford grouping approach knowledge. Finally, we provide illustrations where mnemonics and other visual patterns have been used to help create mental structures to assist with connecting new concepts to current knowledge and previous experiences.

2. METHODS/ANALYSIS

2.1 Jean Piaget Constructivism

Jean Piaget was a psychologist and philosopher. In 1952, he stated that people (children in particular) construct knowledge internally through their actions with the environment [6, 7]. These actions can be mental by enlarging and/or refining existing internal schemas (patterns) or be physical by manipulating an object. The individual learns initially by encountering and then exploring an object or idea. In the beginning, the child, according to Piaget, tries to assimilate this new information into existing schemas or thought structures. Moreover, if the exploration of the idea or object does not match current schemas, the child experiences a state of cognitive disequilibrium and is inspired to mentally accommodate the new experience. Within the process of accommodation, a new schema is constructed from which the information can be assimilated, and then equilibrium can be temporarily reestablished. Moreover, disequilibrium reoccurs each time the child encounters new experiences that cannot be assimilated. It is through this procedure that construction of knowledge takes place.

If there is a minor problem or dissatisfaction with Piaget's definition of constructivism, it is that it tends to consider the assimilation of new information only and does not have the falsifiability criterion. The theory does not give enough weight to the role of the learner or provide for wrong or false mental structures. Additionally, only when the student senses a disequilibrium and confronts experiences that cannot be easily assimilated is he or she required to accommodate the new information and then constructs a new schema. It is through this process that the learner

becomes an active participant in the construction of his or her knowledge.

2.2 Karl Popper Three Worlds View

Karl Popper, born in Vienna, Austria, in 1902, was a philosopher of science and politics. He wrote that "The search for truth, particularly in the natural sciences, no doubt counts among the best and greatest things that life has created in the course of its long search for a better world ... science is our greatest hope; its method is the correction of errors." In his quest for truth, Popper developed a paradigm of knowledge and shaping of reality, which had a basis in his concepts of three worlds and open and closed theories [8, 9].

His World One is the external world of physical states of being and processes as they exist in nature. World Two is a personal interpretation of World One that is processed through senses and experiences. In this regard, World Two is not an exact duplicate of World One. It is subjective in that it is comprised of internal mental states and feelings, whims, volitions, ideas and interpretations. World Two is influenced by environment and culture but from that of a purely subjective point of view. Accordingly, this world tries to make sense of World One. Thus, individuals carry with them in World Two a subjective, internal model of World One.

World Three expresses products and creations of the human mind, such as science, language, art, ethics, books and institutions. World Three interacts with World Two and World One, such that human interpretations (World Two) are necessary to shape natural materials (World One) into meaningful and useful forms (World Three).

Popper suggested in 1972 the following schema to describe the process of establishing truth with falsifiability [8]:

$$P1 \rightarrow TT \rightarrow EE \rightarrow P2.$$

The process begins as a problem (P1) and then advances to a tentative theory (TT). This tentative theory is subjected to errors, in whole or in part, which requires some type of experimental testing or critical discussion. Then a new problem (P2) emerges as a result of the relationship brought about by critical analyses. If the tentative theory occurs to be false, modifications will manifest or another theory will replace it, and the whole process will repeat. Through testing falsifiability, new creations constantly emerge, producing new constructions that will eventually contribute to the adjustment of World Three. Finally, Popper's theories support Piaget's Constructivism, attesting the availability of an open theory that meets the test of falsifiability.

2.3 Bloom's Affective Domain and Bloom's Cognitive Domain

Bloom's Taxonomy, created in 1956, has three groupings or categories, identified as the Affective Domain, Cognitive Domain and Psychomotor Domain. This taxonomy has been designed to promote higher-level thinking, by using such actions, such as characterization, comprehension, application, analyzes, syntheses and evaluations, rather than relying on rote learning only to acquire knowledge [10-12]. In this study, we have used the

first two domains (the cognitive and affective domains) where both can assist students' learning at the academic level. At the completion of learning a new concept, the learner, with these two domains, should have obtained new knowledge and a better attitude toward what has been taught. Finally, the learner should be able to express this expanded state of knowledge through the descriptors of the taxonomies.

3. ILLUSTRATIONS OF MY INDIVIDUAL SYMBOLIC MENTAL STRUCTURES TO IMPLEMENT CONSTRUCTIVISM

In the illustrations below, we use mental structures as a vehicle to provide a connection between a new concept to be learned and a learner's current knowledge and experiences. The components are used to create meaning for processing information by (1) Making connections and associations, (2) Finding patterns in the existing problem, internal structures, (3) Identifying rules, or (4) Abstracting, generalizing principles.

Illustration #1

Physics/Calculus Structures & Associations

$$(1) \int \sin \theta d\theta = -\cos \theta + C \quad (2) \int \cos \theta d\theta = \sin \theta + C$$

$$(3) \frac{d}{d\theta} \sin \theta = \cos \theta \quad (4) \frac{d}{d\theta} \cos \theta = -\sin \theta$$

Outcome: This 2x2 pattern (a mental structure) provides that when equation (1), with its negative sign on the right hand side, is retained, the other three equations (2)–(4) with correct signs can also be recalled correctly as well.

Illustration #2

1. Dirac Equation

$$i\hbar \frac{\partial \psi(\vec{r}, t)}{\partial t} = \hat{H} \psi(\vec{r}, t) = (c\vec{\alpha} \cdot \hat{p} + \tilde{\beta} mc^2) \psi(\vec{r}, t)$$

2. Klein-Gordon Equation

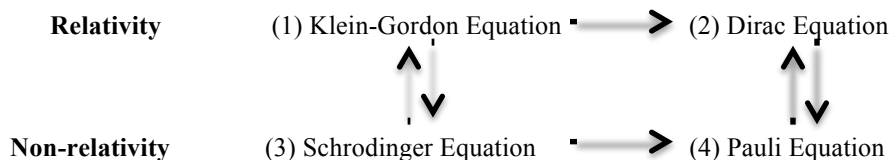
$$\left(\nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} - \frac{m^2 c^2}{\hbar^2} \right) \psi(\vec{r}, t) = 0$$

3. Pauli Equation

$$\left(\frac{1}{2m} \left(\frac{\hbar}{i} \nabla - e\vec{A}(\vec{r}) \right)^2 + V(\vec{r}) + \frac{1}{r} \frac{dV(\vec{r})}{dr} \tilde{\sigma} \cdot \vec{L} - E \right) \begin{pmatrix} \psi_{\uparrow}(\vec{r}) \\ \psi_{\downarrow}(\vec{r}) \end{pmatrix} = 0$$

4. Schrodinger Equation

$$i\hbar \frac{\partial \psi(\vec{r}, t)}{\partial t} = \frac{1}{2m} \left(\frac{\hbar}{i} \nabla - \frac{e}{c} \vec{A}(\vec{r}, t) \right)^2 \psi(\vec{r}, t) + e\Phi(\vec{r}, t)\psi(\vec{r}, t)$$



Outcome: This 2x2 pattern (a mental structure) provides an association that allows the retention of all four equations where one entry alone would be easily forgotten. Moreover, the pattern relates relativistic quantum mechanics in equation (1) and (2) and non-relativistic behavior in equations (3) and (4).

Illustration #3

3A. Organic Chemistry Compounds of Life

The Acronym **NAPLC** and its relationship to NAPLES:

The chief classes of Organic compounds in living matter are Nucleic Acids, Proteins, Lipids, and Carbohydrates. The acronym NAPLC is retained with its association with the well known city NAPLES, and the combination of letters is also remembered about the entire set of compounds.

Outcome: The acronym NAPLC is retained by its association with the famous city of NAPLES.

3B. Organic Compounds Composed Having Functional Groups

The Acronym **HEACCE**:

Hydroxyl (Alcohols), Ethers (Ethers), Aldehyde (Aldehydes), Carbonyl (Ketones), Carboxyl (Acids), and Ester (Ester)
The Acronym **HEACCE** helps in the retention of the entire class of compounds

Outcome: The acronym HEACCE is retained by its association with rhythm "HEA*C*C*E," where one functional group alone would be easily forgotten.

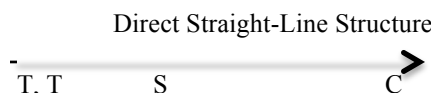
Illustration #4

Space Science Phenomena that Impact Climate Change, other than sun spots cycle

The Acronym **TTSC**:

- Periodic change in the Tilt of the earth's North-South pole axis relative to the sun rays
- The Time of year when the earth is closest to the sun
- The change of the Shape of the earth's orbit

Three Natural Causes of Climate Change When Separate Phenomena Synchronize



Outcome: The acronym TTSC is retained, by its association with the direct straight-line structure of first letters in a string, where one phenomenon alone would be easily forgotten.

4. RESULTS/CONCLUSION

We have revisited Jean Piaget Constructivism theory and Karl Popper Three Worlds view with its falsifiability, where the latter supports the former theory and establishes its approach to cognitive learning. Furthermore, we have restated the importance of Bloom's Affective Domain and Bloom's Cognitive Domain for learning approaches and generalization. We have given illustrated examples of the application of constructivism to assist struggling students (underdeveloped students) to achieve critical thinking abilities. We have touted the importance of and use of both Bloom's taxonomies for the engaged student learner. Moreover, it is the need to remove mental disequilibrium states that require either critical thinking of the individual resulting in an expanded worldview, or a discounting of them while maintaining a disengaging behavior. Additionally, we have stated the three categories of effective mental structures: comparative thinking, symbolic mental structures and logical reasoning, of which the symbolic mental structures have been the focus of this writing. Finally, we have provided cases where mnemonics and other visual patterns have been used to help create mental structures to assist with connecting a new concept to current knowledge and previous experiences. While focusing on underdeveloped students of the physical sciences, the approaches to learning expressed here are transferable to other disciplines, and with the use of these techniques, underdeveloped students can avoid the physical science less. Moreover, it is these collected features that manifest in the self-actuated learner as a reflective critical thinker.

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