Applying Individualized Symbolic Mental Structures With Four Intellectual Utilities For Implementing Cognitive Learning In Two Different Level-Physics Courses

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ABSTRACT

In this paper, we have considered two competing methodologies, which may be used as the first two of four necessary utilities for implementing effective cognitive learning—the type of learning that is achieved by assimilating and accommodating new information with prior knowledge. The first of these methodologies has been provided through constructivism. According to the philosophies of the renowned psychologist and philosopher Jean Piaget, learning a new concept requires the mind to enter a state of disequilibrium and then progress through stages to re-establish a new equilibrium. Human intellect persists in a dynamic equilibrium state, while maintaining self-satisfaction and contentment. This equilibrium state allows reflective thought and reassurance within an individual about what he or she already knows. Moreover, according to Piaget, a student is thrown into a state of mental disequilibrium with the onset of receiving and assimilating a new concept, and it is a desire to remove the disequilibrium that results in cognitive learning. The second method for implementing cognitive learning has been advanced by the lesser-known Soviet Psychologist Lev Vygotsky, who expressed the notion that cognitive learning does not occur from removing a state of disequilibrium, but rather, it occurs from Cognitive Development instead. Cognitive Development occurs from the integration of both learning and an individual's sociocultural development, and as an outcome, manifests as an effective cognitive learning procedure. Additionally, Vygotsky has provided the philosophy that the nurturing of students is required in order to have both learning and sociocultural development to occur concurrently, instead of having only a natural assimilation and accommodation from a disequilibrium as asserted by Piaget. In this regard, we have reviewed briefly Jean Piaget's Constructivism, Lev Vygotsky's Cognitive Development Adaptation, Karl Popper's Three Worlds View Hypothesis, with its falsifiability component, and Bloom's affective and cognitive domains while considering each structure as a separate utility. Lastly, we have presented our notion of applying Individualized Symbolic Metal Structures (ISMSs), which allows through these methods the first-step effort beyond rote memorization to achieve cognitive learning.

1. INTRODUCTION

Physics majors constantly engage new concepts to expand their understanding, while the early-career matriculating non-science majors, often having underdeveloped mathematical skills, do not engage effectively in mathematics related courses, or at most, they do so minimally [1-3]. We readily observe students' confidence and maturity levels variation in courses such as PHY 102 (Physical Science II), and PHY 331 (Intermediate Electricity and Magnetism I) [4,5]. Our primary concern is to comprehend the differences between the students' understanding levels while taking these two courses and develop techniques to maximize each student's cognitive learning.

In this regard, we recognize that physics majors, as self-actuated learners, autonomously develop techniques for cognitive learning via schemas, including the method that we call ISMSs that is presented here. This method for implementing cognitive learning is provided directly by Piaget's Constructivism. On the other hand, the early-career matriculating non-science major often needs more assistance for implementing cognitive learning, which can be made available to him or her by using a deviating method that is provided here by Lev Vygotsky's Cognitive Development Adaptation. Using this latter method, which is a nurturing approach, we observe that the early-career matriculating non-science major benefits more effectively from cognitive development instead of direct cognitive learning. In this case, the student must be guided in the development of necessary ISMSs, since he or she is less likely to cognize individually while in courses like PHY 102. These structures (or schemas) are in the form of memory mnemonics, acronyms, and a few other mental structures (mental thought patterns) of the mind that can assist students to engage new concepts and retain them long enough in time to develop connections between the new information, and his or her current knowledge and previous experiences [6]. Because of variations in shapes of these patterns, when written, we call them "mental hooks," "mental straights," "mental S's," or "mental waves." All students in the sciences, including the self-actuated learner

and the early-career matriculating non-science majors, may benefit from these concrete structures or thought patterns.

This paper provides, on one hand, a rationale for favoring the use of Piaget's Constructivism theory for implementing direct cognitive learning in intermediate and advanced physics courses, such as, PHY 331 (Electricity and Magnetism I) and, on the other hand, the use of Vygotsky's Cognitive Development Adaptation in courses for early-career matriculating non-science majors, such as, PHY 102 (Physical Science II). Moreover, each of these methodologies, as utilities, is separately supported by Karl Popper's Three Worlds view theory, Bloom's affective and cognitive Domains and our notion of applying ISMSs as a first-step effort beyond memorization to achieve cognitive learning. In this regard, cognitive learning is where new knowledge is assimilated based on the addition to the existing understanding the student already has.

We have arranged this paper in the following manner: Firstly, we give in section 2 (the Methods/Analysis section) a brief narrative on the attributes of Jean Piaget's Constructivism, followed by a similar presentation on Lev Vygotsky's Cognitive Development Adaptation. Then, Karl Popper's Three Worlds View is described[7, 8], followed by a review of Bloom's affective and cognitive domains. Section 3 illustrates selected ISMSs, from our own origination, that can be used in the aforementioned courses. Finally, Results/Conclusions and Acknowledgments are given in Sections 4, and 5 respectively, with References given in Section 6.

2. METHODS/ANALYSIS

2.1 Jean Piaget's Constructivism

Jean Piaget, who was a renowned psychologist and philosopher, did his most important work in the early middle years of the 20th century. In 1952, he stated that children construct knowledge internally through their actions with the environment [9]. These actions, he indicates, 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 objects and then by exploring ideas. Initially, the child tries, according to Piaget, to assimilate this new information into existing schemas or mental structures. Moreover, if the exploration of the idea or object does not match current schemas, the child experiences a state of mind disequilibrium and is, therefore, inspired to accommodate mentally to the new experience. Within the process of accommodation, a new schema is constructed from which the information can be assimilated, and then the equilibrium of the mind, as a required state, can be temporarily re-established. Moreover, a state of disequilibrium reoccurs each time the child encounters new experiences that cannot be readily assimilated. It is through this process that the student constructs and assimilates new knowledge in direct cognitive learning.

If there is a minor problem or dissatisfaction that we recognize with Piaget's Constructivism, it is that it tends to consider the assimilation of new information only and does not have a falsifiability component or truth criterion. Additionally, the theory does not give enough weight to the role of the learner or to his or her prior experiences or mental conditioning. Piaget's theories assert that only when the student senses disequilibrium and confronts experiences, which cannot be easily assimilated, he or she is required to accommodate to the new information and then constructs a new schema in the mind. It is through this process that the learner becomes an active participant in the construction of his or her knowledge. While this style of cognitive learning is quite effective for self-actuated learners, as those we observe in courses like PHY 331, it is not totally effective for the early-career matriculating non-science majors in our PHY 102 classes. Another methodology is more appropriate for this latter group of students.

2.2 Lev Vygotsky Cognitive Development Adaptation

Lev Vygotsky (November 1896 – June 1934) was a Soviet psychologist, who advanced selected theories on cognitive processes that are gaining popularity. Vygotsky posits the notion that learning and personal development are intricately connected and inseparable [10]. Additionally, his theories contradict Piaget's claims on content acquiring and his universal stages of development. Also, Vygotsky asserts more emphatically that cognitive development varies across cultures, while Piaget expresses that cognitive learning is essentially universal and places less emphasis on social factors as contributing to cognitive development. Vygotsky's position for implementing cognitive development is that of nurturing the student to the point of integrating sociocultural development and learning to yield indirect cognitive learning. Unlike Piaget's stance, which states that natural development occurs first and cognitive learning follows afterward, Vygotsky has the two aspects intertwined.

2.3 Karl Popper Three Worlds View

Karl Popper, born in Vienna, Austria, in 1902, was an Austrian-British philosopher of science and politics, and his important works were dedicated to examine ways of searching for and testing accurate representations of the world, which resulted in his Three Worlds View (our third intellectual utility). According to Harlow, et. al. [7], Popper in 1994, in his quest for the truth, developed a paradigm of knowledge and a shaping of reality that were based on his concepts of three worlds, and his open and closed theories. His method [11,12] is the correction of errors or wrong knowledge.

Popper's World One is the external world of physical states of being and processes as they exist in nature. It is the world of things and events. His World Two is the individual's interpretation of World One that has been filtered through the senses and experiences. Additionally, World Two is not an exact description or replica of World One. World Two for a student has been influenced by the environment and culture, which necessarily makes it not an exact duplicate. It is subjective in that it is comprised of internal mental states and feelings, whims, volitions, ideas and interpretations. Accordingly, World Two tries to make sense of World One (the world of things and events.) Thus, Popper states that individuals have within themselves, from World Two, a subjective, internal model of World One, having variated states of the truth.

Popper's World Three expresses development or outcomes, such as, the products and creations of the human mind, including the sciences, languages, arts, ethics, books and institutions. In this regard, World Three interacts with (considers) World Two and World One, in such a way that the interpretations of World Two are necessary to shape the natural raw materials into meaningful and useful forms from World One as manifested in World Three.

Resulting from his three worlds theory, and his open and closed theories, Popper suggested in 1972 the following schema to describe the process of establishing truth where falsifiability may exist (corrections for wrong thinking) [7]:

$$P1 \rightarrow TT \rightarrow EE \rightarrow P2,$$

where (P1) is a problem to be solved that advances to a tentative theory (TT). This theory is subjected to errors, in whole or in part, which requires some experimental investigations leading to testing of critical discussions, and the elimination of errors expressed as (EE). Then a new problem (P2) emerges as a result of careful analysis. If the tentative theory occurs to be false, modifications will follow or another theory will replace it, and the whole process will repeat. Moreover, through testing falsifiability, new creations constantly emerge, producing new knowledge that will eventually contribute to the adjustment of World Three. Finally, Popper's theories support Piaget's Constructivism, while attesting the availability of an open theory that meets the test of falsifiability.

In a similar manner to Popper's theories under-girdling Piaget's constructivism, which operates to uncover the truth in cognitive learning, his theories can, as well, support Vygotsky's cognitive development adaptation principles. Thus, each methodology can separately benefit from Popper's theories.

2.4 Benjamin Bloom's Affective Domain and Bloom's Cognitive Domain

Bloom's Taxonomy, our fourth intellectual utility, as created in 1956, has three categories, identified as the Affective Domain, the Cognitive Domain and the Psychomotor Domain. This taxonomy has been designed to promote higher-level thinking, by such actions, as characterization, comprehension, application, analysis, synthesis and evaluation, rather than relying on rote recall (or memorization) only to acquire new knowledge [13, 14]. We use both the cognitive and affective domains at the academic level to implement effective cognitive learning. Upon the completed learning of a new concept, the mentally engaged learner, with these two domains, should have obtained new knowledge and a richer appreciation for what has been taught. Finally, such a student should be able to express and illustrate his or her expanded state of knowledge through this intellectual utility.

3. ILLUSTRATIONS OF OUR INDIVIDUAL SYMBOLIC MENTAL STRUCTURES (ISMSs) TO IMPLEMENT COGNITIVE LEARNING

In the below illustrated ISMSs, we use mental structures as a mean to provide a connection between a new concept to learn 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 (mind maps) in the existing problem in its internal structures, (3) Identifying rules, or (4) Reifying or making concrete abstractions and generalized principles.

Illustration #1

Straight-Line Multiplication and Division As Needed (SLMADAN) for simple mathematical problems, such as the relationship between power, in watts, that is provided to a resistor carrying current I, in amp, when a voltage V, in volt, is applied. The equation is P=IV, and the product is implemented and retained through a reversed hook pattern (not shown) or the heat flow Q, in watts, when a material of mass m, in kg, incurs and temperature change ΔT, in Celsius, with c being the specific heat, then $\Delta T = Q / c \cdot m.$ The concept and equation manipulation are retained via the **memory acronym SLMADAN**.

Illustration #2

Radioactive Decay Processes: **ECAPE** is an individualized memory acronym for **E**lectron **C**apture **A**nd a **P**ositron **E**mission as the final two radioactive decay processes after the well-known first three processes are given, which are, the alpha, beta, and gamma processes. The first-three are easier to remember and retain. This memory acronym provides a pattern to cognize and to retain all five decaying processes. (an S shape-pattern not shown is possible)

Illustration #3

Physics/Calculus
Structures & Associations

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

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

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

Illustration #4
4A. Organic Chemistry Compounds of Life

The memory acronym **NAPLC** and its relationship to NAPLES (A Well-Known City)**:**
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 therefore remembered about the entire set of life compounds.

Outcome: The memory acronym NAPLC is understood and retained by its association with NAPLES.

4B. Organic Compounds Composed Having Functional Groups

The Memory Acronym **HEACCE:**
Hydroxyl (Alcohols), Ethers (Ethers), Aldehyde (Aldehydes), Carbonyl (Ketones), Carboxyl (Acids), and Ester (Ester)
The memory 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 #5
Space Science Phenomena that Impact Climate Change, other than the sunspot cycle. The memory acronym **TTSC:**

- Periodic change in the **T**ilt of the earth's North-South pole axis relative to the sun rays
- The **T**ime of the year when the earth is closest to the sun
- The change of the **S**hape of the earth's orbit

Three Natural **C**auses of Climate Change When Separate Phenomena Synchronize

Direct Straight-Line Structure

T, T S C

Outcome: The **memory 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's Constructivism theory, Lev Vygotsky's Cognitive Development Adaptation procedure, and Karl Popper's Three Worlds view with its falsifiability component, where each of these three structures can contribute as separate intellectual utilities. Furthermore, we have restated the importance of Bloom's Affective Domain and Bloom's Cognitive Domain for implementing cognitive learning approaches as a fourth useful intellectual utility for cognitive learning. We have given illustrated examples of the application to either Piaget's Constructivism for self-actuated learners to implement directly cognitive learning and Vygotsky's Cognitive Development to assist early-career matriculating non-science majors to achieve the same, but as an indirect cognitive learning procedure. Additionally, We have expressed the importance and use of Bloom's taxonomy (both the affective and cognitive domains). Additionally, we have illustrated the importance of using ISMSs as a first-step beyond rote memorization for achieving effective cognitive learning. Specifically, we have given several ISMSs, using memory mnemonics and other visual patterns (mind maps) for reification purposes. While our focus has primarily been on the early-career matriculating non-science majors in PHY 102 (Physics Science II) and the Physics Majors in PHY 331 (Electricity and Magnetism I), the methodologies expressed here on how to implement cognitive learning are thought to be applicable to other courses in physics and other disciplines.

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6. REFERENCES

[1] Garner, B. K., "Getting to Got It: Helping Struggling Students Learn How To Learn", ASCD, Alexandria, VA, 2007.

[2] Borg, Simon, "Teacher Cognition and Language Education: Research and Practice," Bloomsbury Publishing, New York, 2009.

[3] Edwards, M. E., "Recognizing the Need for Rich Contextualization in the Classroom and Applying It With Modified Bloom's Cognitive Domain Taxonomy For Successful Teaching of Physics 106 (Physics II – electricity, magnetism, and Light)," Journal of Systemics, Cybernetics And Informatics, 12 (3), 22-28 (2014).

[4] Konrad B. Krauskopf and Arthur Beiser, "The Physical Universe," McGraw-Hill, Co, 16th edition, 2017.

[5] David J. Griffiths, "Introduction to Electrodynamics," Pearson Education, Inc., publishing as Prentice Hall, 4th edition, 2013.

[6] Edwards, M. E., 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, Journal of Systemics, Cybernetics And Informatics, 15(6), 130-134 (2017).

[7] Harlow, S., R. Cummings, S. M. Aberasturi, Karl Popper and Jean Piaget: A Rationale for Constructivism, The Educational Forum, **71** (1): 41-48, 2007.

[8] Lesh R., H. M. Doerr G. Carmona & M. Hjalmarson, Beyond Constructivism. Mathematical Thinking and Learning 5 (2/3): 211–33, 2003.

[9] Piaget J. The origins of intelligence in children, trans. M. Cook. New York: International Universities Press, 1952.

[10] Vygotsky, L. S. "Thought and Language", Cambridge MIT Press, 1962.

[11] Popper K. R., Objective knowledge: An evolutionary approach. Oxford: Oxford University Press, 1972.

[12] Popper K. R., In search of a better world: Lectures and essays from thirty years, trans. L. J. Bennett. London: Routledge, 1994.

[13] Anderson, L. W., and David R. Krathwohl, et al (Eds.) "A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives," Allyn & Bacon, Boston, MA (Pearson Education Group), 2001.

[14] Divya, S., Edwards, M. E., Khan, S., Vilasini, A., Effectiveness of a Constructivistic Multimedia-Learning Package on Shaping and Guiding Students' Attitudes Toward Physics, Journal of Systemics, Cybernetics And Informatics, 14 (3), 22-28 (2016).