THE SYSTEMIC APPROACH TO TEACHING AND LEARNING [SATL]: A 10-YEAR REVIEW

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ABSTRACT

The Systemic Approach to Teaching and Learning (SATL) is based on constructivist principles and involves the creation of closed cluster concept maps called systemic diagrams. The SATL technique encourages deep learning, as opposed to rote learning. Examples in the use of SATL methods in teaching chemistry are presented. Experimental evidence collected in Egyptian schools is presented to illustrate the efficacy of SATL methods on student achievement. It is suggested that SATL methods mimic our current understanding of how the human brain functions, as the basic reason that SAL methods are successful. [*AJCE*, *1(1), January 2011*]

INTRODUCTION

About a decade ago the authors formulated their basic ideas on the Systemic Approach to Teaching and Learning (SATL). In the intervening time, SATL methods have been refined and their usefulness in disciplines other than chemistry has been established. Most of the developmental efforts on SATL methods have been expressed in chemistry-oriented subjects at virtually every educational level. We present here the current status of SATL methods.

Our primary professional interests have always been helping teachers teach and students learn more effectively, and we believe the SATL technique described here has additional benefits to societies that face issues of globalization. Economics, media, politics, and banking are among the human activities that have achieved a global, as opposed to a regional or a local, perspective. Science education—that process by which progress in science is transmitted to the appropriate cohort of world citizens—must be sufficiently flexible to adapt to an uncertain or, at best, ill-defined global future. That future, however, ultimately must include an appreciation of the vital role that scientists and chemists, in particular, play in human development. Thus, the future of science education must reflect a flexibility to adapt to rapidly changing world needs. It is our thesis that a systemic view of science with regard to principles and their internal (to science) interactions as well as the interactions with human needs will best serve the future world society. Through the use of a systemic approach, we believe it is possible to teach people in most areas of human activity—economic, political, and scientific—to practice a more global view of the core science relationships and of the importance of science to such activities.

As a start, we suggest the development of an educational process based on the application of "systemics," which we know (*vide infra*) can affect both teaching and learning. The use of systemics can help students begin to understand interrelationships of concepts in a greater context, a point of view, once achieved, that ultimately should prove beneficial to future citizens of a world that is becoming increasingly globalized. Moreover, if students learn the basis of the systemic process in the context of learning chemistry, we believe they will doubly benefit; learning chemistry and learning to see *all* subjects in a greater context. In this regard, anecdotal evidence exists (*vide infra*) that students who learn chemistry using SATL techniques are able to transfer that learning process to other disciplines.

THE ROOTS OF SYSTEMICS

The basic SATL concepts are derived from Constructivist ideas. A number of excellent reviews of the current status of Constructivist thought are available, among which is the book edited by Fosnot (1) that can guide the interested reader through the milieu of teaching and learning strategies that incorporate constructivist ideas. Here we are interested in the historic roots of constructivism from which these modern ideas have evolved.

Constructivism. The concept of constructivism is like a great river, both have multiple, important roots; the choice of the single most important root does not accomplish much for understanding. Historically, modern constructivist ideas can be traced back to the 18th century philosopher, Giambatlista Vico who maintained that humans can understand only that which they themselves have constructed (2). The “modern” roots of constructivism go back to Jean Piaget (3) who, in 1955, first used the term “constructivist.” A number of workers have contributed to these ideas, including John Dewey (4,5). More recent scholars include Von Glasersfeld (6), Vygotsky (7), and Bruner (8). Constructivist ideas have appeared also in the chemical education literature (9-11). We choose here to pick up the thread of constructivist ideas that can be attributed to Ausubel (12,13).

In the early 1960s, when behaviorist theory prevailed among educational psychologists, Ausubel published a book entitled *The Psychology of Meaningful Verbal Learning* (13) in which he elaborated on constructivist ideas. Ausubel introduced the idea of *meaningful* learning (as opposed to rote learning). Contemporary assimilation theory stems from Ausubel's views of human learning that incorporates cognitive, affective, and psychomotor elements integrated to produce *meaningful* learning. To Ausubel, meaningful learning is a process in which new information is assimilated into a relevant aspect of an individual's existing knowledge structure and which, correspondingly, must be the result of an overt action by the learner. Using Ausubel's words, new knowledge is *subsumed* by the learner into his/her current knowledge structure. Teachers can encourage this choice by using a variety of tools. It is postulated that continued learning of new information relevant to information already understood produces constructive changes in neural cells that already are involved in the storage of the associated knowledge unit. An important component in Ausubel's writing has been the distinction he emphasized between the rote—meaningful learning continuum and the reception-discovey continuum for instruction. The orthogonal relationship between these two continua is illustrated in Fig. 1.

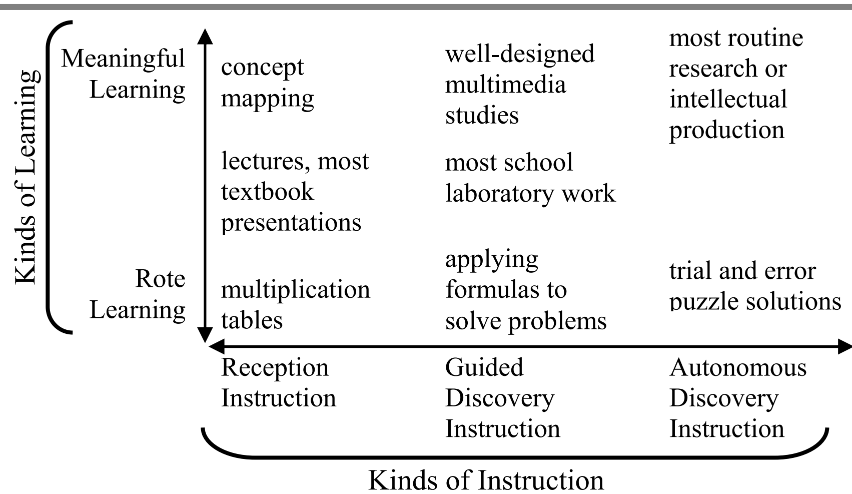

Fig. 1. Examples of instructional techniques displayed on the orthogonal rote-meaningful learning continuum and the reception-discovery continuum. [Adapted from Novak (3).]

According to Ausubel, the essence of the meaningful learning process is that symbolically expressed ideas are related to what the learner already knows. Meaningful learning presupposes that the learner has a disposition to relate the new materials to his or her cognitive structure and that the new material learned will be potentially meaningful to him or her. In other words, it takes an overt act by the learner to make learning meaningful.

Concept maps. Concept Mapping is a tool developed by Novak and Gowin (14,15) designed to reveal interrelationships among concepts. A concept map is a concise, two-dimensional representation of a learner's multi-dimensional concept/prepositional framework of a particular domain of knowledge. As an example of a concept map, consider Fig. 2, which maps the concepts of atoms, nuclei, electrons, protons, and neutrons. Concepts are linked by words that establish propositions involving the linked concepts, e.g., "atoms contain nuclei." The concepts with their linking relationships now become visible in a concept map showing the organization of concepts in the learner's cognitive structure. Concept maps can reveal misconceptions that may exist in a student's mind; they also can be employed by teachers to illustrate the relationships that the teacher wants the student to learn. Thus, concept maps are tools that both students and teachers can use to further their own purposes—teachers to teach and assess and students to learn.

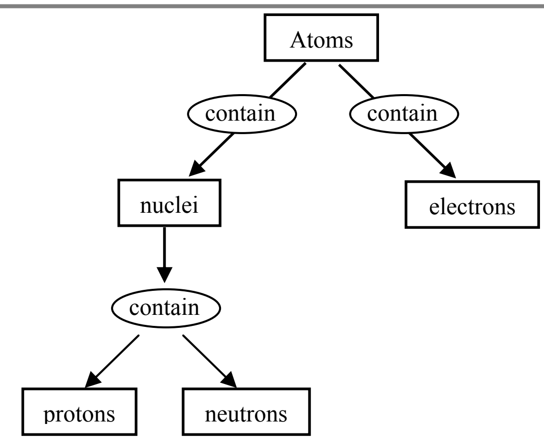

Fig. 2. An example of a concept map relating the concepts of atoms, nuclei, electrons, protons, and neutrons.

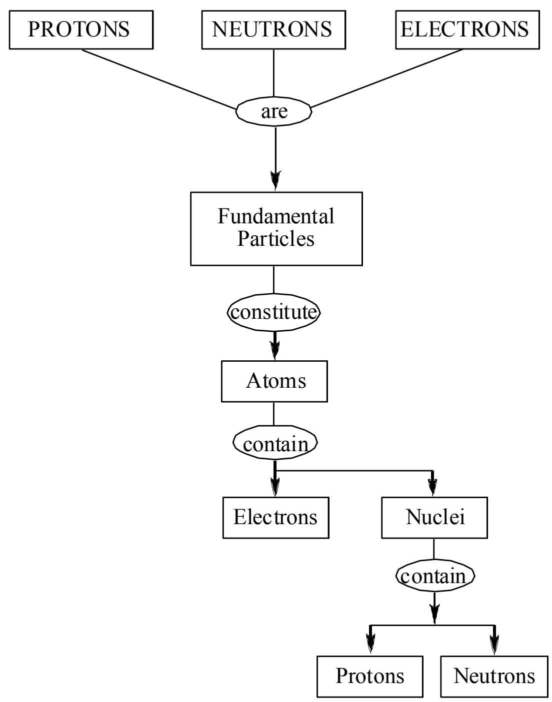

Fig. 3. A concept map that relates the concepts of protons, neutrons, electrons, fundamental particles, atoms, and nuclei.

Care must be taken to recognize that several different, but acceptable, maps may be used to illustrate relationships among the same group of concepts. Consider the concept map shown in Fig. 3 that involves an acceptable, but different relationship amongst the concepts shown in Fig. 2. Note that the arrangement of the same concepts (except for the "fundamental particle concept) is different, but acceptable (correct). Note that the introduction of the "fundamental particle" concept produces a concept map that is, perhaps, intuitively "less esthetic" than that in Fig. 2, but it is not "wrong". It could be argued that the concept map in Fig. 3 contains redundancies and, hence, is less "desirable" than that in Fig. 2. On that basis, it might not receive full marks, but this is a judgment call.

Our interest in concept maps here is their relationship to the systemic diagrams that are a key element in the SATL technique as representations for teaching and learning chemistry in a global manner.

CLOSED CLUSTER CONCEPT MAPS

In the systemic approach, we strive to organize subjects in "closed-cluster concept maps," (Fig. 4) which, in contrast to standard concept maps, do not continue to proliferate in ever-expanding tree-like structures (e.g., Fig. 3). Notice that, in the closed concept structure (Fig. 4), there is also an implication of multi-pathway relationships that may or may not be important to the student (or teacher) at a given moment of understanding, but which may be "revealed" at a later time. In this sense, closed concept clusters are complete unto themselves, which is to be contrasted with "standard" concept maps. Thus, all the relationships in a closed cluster need not be explicitly taught, but they are there to be used as necessary, e.g., perhaps for assessment.

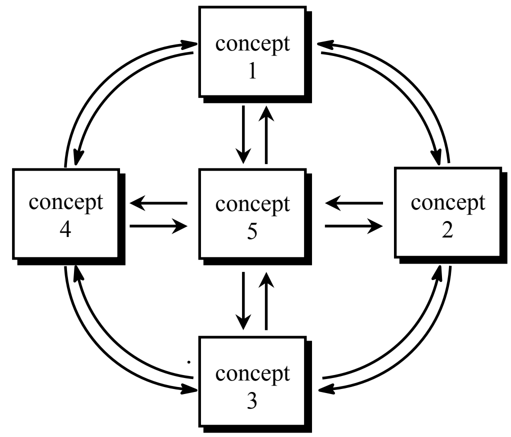

Fig. 4. A diagrammatic representation of a closed concept cluster.

THE SATL TECHNIQUE

Linear *vs.* Systemic Teaching. The usual approach to teaching a subject involves arranging the associated concepts in a linear manner (Fig. 5A). For the sake of discussion, assume there are four (4) concepts to be taught. In the linear approach there may be several ways to approach teaching these four concepts in the example shown. The choice of the specific linear approach is often highly subjective and it may obscure relationships that students can understand. The SATL technique involves organizing the concepts associated with a subject to show the interrelationships among the concepts (Fig. 5B). A diagrammatic representation of these two approaches to teaching is shown in Fig. 5.

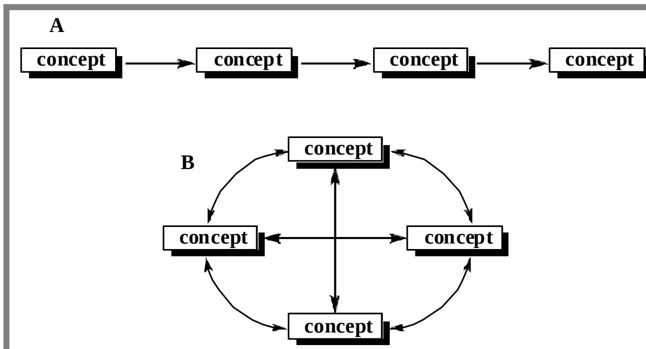

Fig. 5. Diagrammatic relationship between (A) a linear approach, and (B) the systemic approach in the presentation of concepts.

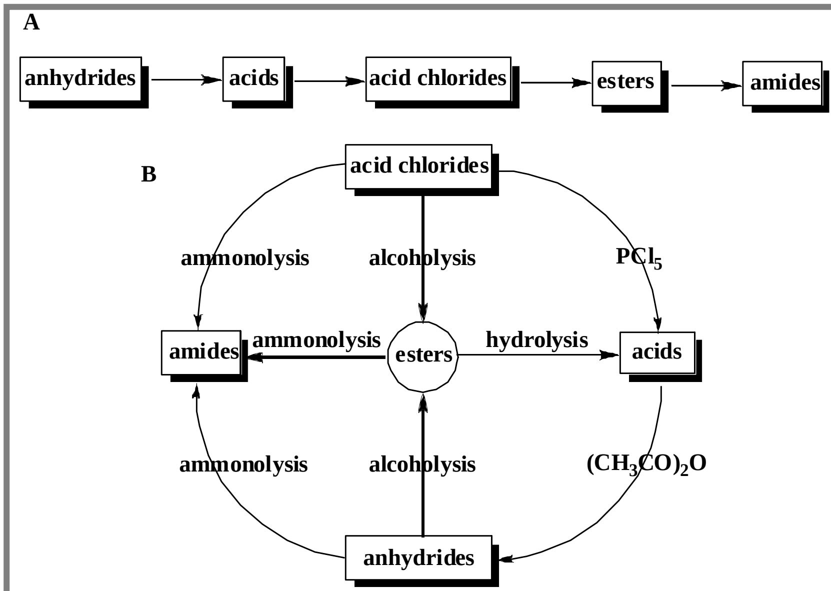

Fig. 6. The presentation of the important concepts associated with (A) carboxyl chemistry as presented linearly, and (B) systemically.

We introduce now the basic ideas of the systemic approach to teaching and learning. Although the SATL technique has been applied to a variety of subjects, we choose to use examples from chemistry, the subject in which we were trained. By "systemic" we mean an arrangement of concepts or issues through interacting systems in which all relationships between concepts and issues are made explicit to the learner using a concept map-like representation. In contrast with the usual strategy of concept mapping, which involves establishing a static hierarchy of concepts, our systemic approach strives to create a more-or-less dynamic system of an evolving "closed system of concepts"—a concept cluster (Fig. 6B shows an example that stresses the interrelationships associated with the chemistry of organic acids). Further, our use of the term "systemics" stresses recognition of the *system* of concepts that form the cluster of concepts under consideration, and the dynamic evolution of the concept cluster in the hands of the teacher. Systemics means the creation of closed-cluster concept maps for the purposes of helping students learn; systemics is an instructor-oriented tool and, hence, requires teacher and student materials to be created about the closed-cluster concept map strategy. A more complete description for creating systemic diagrams appears in the next article.

Although we have produced and used a number of closed-cluster systemic maps on a variety of chemistry-oriented subjects, we illustrate the processes with a module in organic chemistry that was used in an experiment to establish (16) the efficacy of our approach.

Operational Systemics. Having established the underlying relationships between constructivist theory and concept maps with SATL ideas, we now turn to illustrate some of the details of how systemic diagrams are used in teaching. Imagine that a group of students studying organic chemistry are part way through the course having studied the hydrocarbons, alcohols, alkyl halides, aldehydes, and ketones and that they are ready to start their studies of carboxylic acids. The information to be learned could be organized into an appropriate systemic diagram (or, perhaps, it already exists as such) which we will call SD_0. In Ausubel's terms, SD_0 contains the prior knowledge upon which the new knowledge will be attached. A new systemic diagram can be started from an appropriate part of SD_0 to incorporate a new relationship characteristic of carboxylic acids; call this "new" (or, beginning diagram) SD_1. SD_1 can now be altered with another new characteristic relationship of carboxylic acids to form SD_2, and so on to SD_3, SD_4, etc., to the final systemic diagram, SD_f. SD_f now becomes the prior knowledge for the next systemic

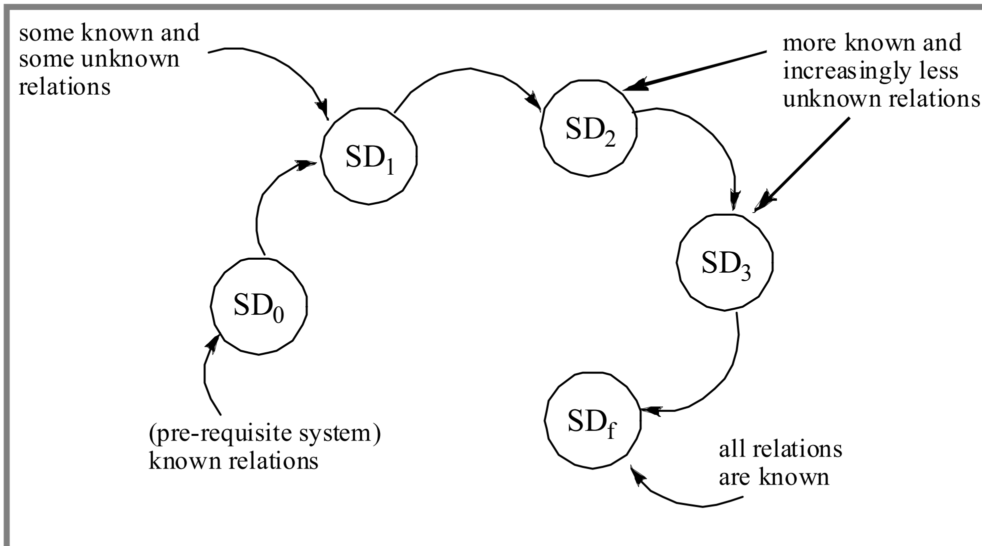

Fig. 7. Diagrammatic representation of SATL methodology.

diagram. A diagrammatic representation of this evolutionary process to the final systemic diagram is shown in Fig. 7.

As an example, Fig. 8 is the *entire* systemic diagram for *all* of the reactions of carboxylic acids. At this point in the evolution of that systemic diagram, the relations indicated

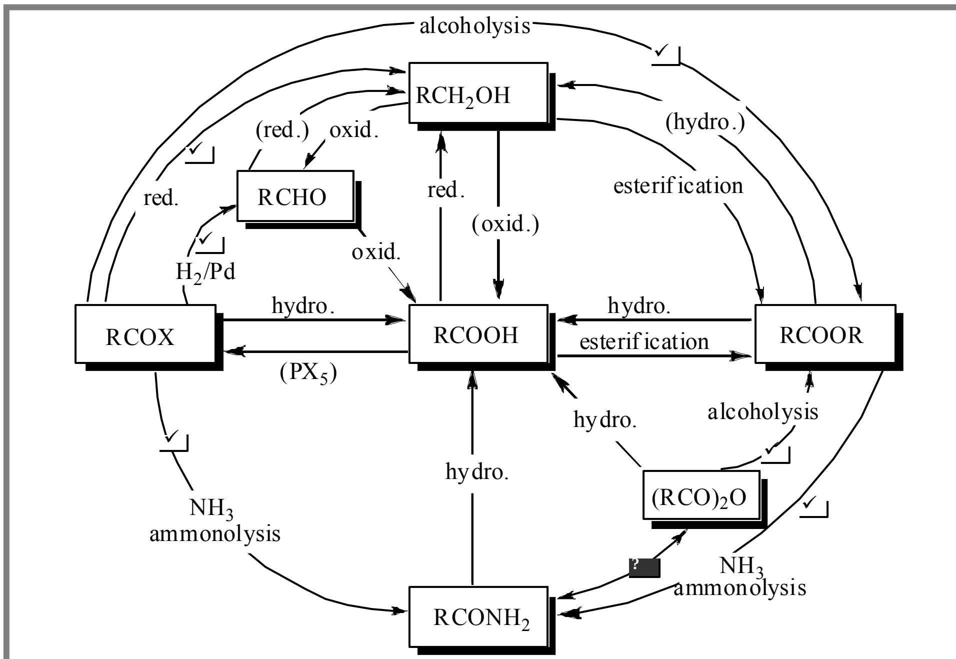

Fig. 8. A systemic diagram for carboxylic acids. In this diagram, the reactions ✓ have been developed by the teacher with his/her students. The reaction marked ? represents the current focus of discussion.

by ✓ have been developed by the teacher with his/her students whereas the symbol ? represents the current focus for the classroom discussion. In the current example of the operational use of systemics, Fig. 8 represents *all* of the chemical relationships for the carboxylic acids that are to be taught in this class. [Note: Fig. 8 may not truly represent *all* the extant chemical relationships *known* for the carboxylic acids.] So, from the point of view of this example, Fig. 8 represents the content goals for this class as have been prepared by the teacher.

EVALUATION OF SYSTEMIC TECHNIQUES

The efficacy of using the SATL method to help students learn chemistry has been studied using controlled experiments (16,17) in which the achievement of student learners exposed to SATL methods was compared with that of a similar cohort of students taught in the conventional linear manner. Students (*n*=429) in six (6) secondary schools in the Cairo and Giza (Egypt) school districts who were studying organic chemistry were involved in this experiment.

The SATL intervention occurred over a two-week period and was focused on the chemistry of carboxylic acids which appeared in the middle of the standard curriculum after hydrocarbons, alcohols, aldehydes, and ketones, but before amines. Standard laboratory experiences were also included in the material used in this study. The control group (*n*=159) was taught using the standard linear approach to the subject. A systemic-oriented module on carboxylic acids was created for this study and was used by the experimental group (*n*=270).

All teaching and administrative personnel—thirty (30) people total—who had a legitimate interest in the students involved (Egyptian Ministry of Education represented by content experts; Educational Districts, represented by local inspectors; and Educational Zones, represented by General Inspectors). Four (4) teachers with 15-18 years of experience were involved in teaching with SATL materials, and eight (8) teachers with 20-26 years of experience taught the control group using standard linear-oriented materials. All personnel—teachers and administrators—attended an 18-hour training session; the teacher cohort attended the full workshop whereas the administrators attended only those sessions that pertained to their responsibilities.

The assessment strategy included a comparison of student scores on appropriate examinations as well as survey instruments and interviews that probed the affective domain. A pre- and post-test strategy was employed; tests involved a mixture of question types—multiple choice, short answer, and completion of systemic diagrams. The tests were scored by the teachers using supplied answer keys.

Several important general points flow from this well-constructed and carefully conducted experiment. Both the control and the experimental classes (Table 1) exhibited similar pre-intervention mean scores for linear questions—those kinds of questions that are typically asked in courses taught by traditional methods. This result might not be unexpected, since both cohorts were taught the previous (prerequisite) content materials by traditional methods.

Table 1 Student scores on tests by type of instructional approach

		Pre-Test Scores			Post-Test Scores		
Instructional Approach	Group Type	Means	Standard Deviation	Standard Error Mean	Means	Standard Deviation	Standard Error Mean
Linear							
	Control (*n* = 159)	44.73	15.13	0.18	46.16	15.37	0.85
	Experimental (*n* = 270)	37.11	18.84	0.51	91.32	13.72	0.31
Systemic							
	Control (*n* = 159)	16.63	13.44	0.14	20.1	14.24	0.97
	Experimental (*n* = 270)	12.05	11.42	0.12	82.88	14.56	0.75

Post-intervention mean test scores were higher for both groups of students, as might be expected for any learning environment. However, the mean scores for the experimental group were markedly higher than those for the control group. A similar pattern evolved for systemically-oriented questions and, perhaps as expected, the mean scores for the systemically-oriented questions were considerably more improved for the experimental group who were, of course, taught from the systemic point of view. Recall that systemics stresses the acquisition of the higher order cognitive skills as defined by Bloom (18)(19).

Students who were taught by instructors using SATL techniques were more successful on the final examination than students who were taught linearly, success being defined as achieving at least 50% on the final examination; note that this definition of "success" is that commonly used in these school districts. By this measure, approximately 80% of the experimental group were successful, but only 10% of the control group reached this level of success.

The analyses of student survey data (paper and interviews) indicate a positive perception that SATL methods improved the students' ability to view the chemistry of the experimental module from a more global perspective and preliminary results indicate that the SATL approach affected the way students approached the subsequent subjects in the course that were taught traditionally in the chemistry curriculum. Interview data suggest that many students applied the SATL techniques to their other studies. An interesting insight from teacher interviews expressed an opinion they could create systemic-oriented teaching materials in biology and physics, which they were also qualified to teach.

Similar demonstrable success in student achievement using SATL methods in other chemistry courses has been reported for the following subjects (see Table 2): aliphatic chemistry (21); (22); (23), aromatic chemistry (24); heterocyclic chemistry (25); (26);(27);analytical chemistry (28) and physical chemistry (29).

SYSTEMICS AND OTHER DISCIPLINES

Although the successful application of systemics has been well demonstrated in the chemical sciences (Table 2), the literature contains reports of the successful use of SATL methods in linguistics (Arabic), mathematics, medical sciences, law, agricultural sciences, and engineering; references to these works are all in Arabic and can be found at the SATL Central website (SATL website).

Table 2: SATLC Materials in Chemistry

Subject Matter	**Student Level**	**Duration/Date**	**Presentation Venue**
A unit on Carboxylic acids and their derivatives (17)		9 Lessons Two Weeks March 1998	Presented at the 15th ICCE, Cairo, Egypt, August 1998
A Unit on Classification of Elements (20)		15 Lessons Three Weeks October 2002	Presented at the 3rd Arab Conference on SATL, April 2003
A Textbook entitled “Aliphatic Chemistry” (21,22,23)	University Level -Pre-Pharmacy -Second year, Faculty of Science	One Semester Course 16 Lectures, 32 hours During the academic years 1998/1999, 1999/2000, 2000/2001	Presented at the 16th ICCE, Budapest, Hungary, August 2000
A Textbook entitled “Heterocyclic Chemistry” (25, 26,27)	-Third Year, Faculty of Science	10 Lectures, 20 hours During the academic years 1999/2000, 2000/2001	Presented at the 7th ISICHC, Alex., Egypt, March 2000. 9th ISICHC Sharm El-sheikh, Egypt, December 2004
A Unit on Benign Analysis (28)	-First Year Faculty of Science	One Semester Lab Course, 24 hours (2 hours/week) During academic year 2001-2002	Presented at the 17th ICCE, Beijing, August 2002
A Texbook entitled “Aromatic Chemistry” (24)	-Second Year Faculty of Science	One Semester course (16 lectures, 32 hours) During the academic year 2000/2001	Presented at the Malta 3rd Conference on Frontiers of Chemistry Teaching and Research in the Middle East, Istanbul, December 2007

[a] See also (Ref. 34)

BRAIN FUNCTION

The demonstrable success of SATL methods and constructivist theory can be understood in terms of our current understanding of how the brain works. For the past several decades, cognitive psychologists and physical scientists have developed a variety of techniques to map the functioning brain as it performs various tasks (30); (31); (32); (33). Non evasive probes that have been employed in establishing brain behavior include, computed tomography (CT), computer axial tomography (CAT), magnetic resonance imaging (MRI), functional magnetic imaging (fMRI), positron emission tomography (PET), single-photon emission computer tomography (SECT), diffuse optical imaging (DOI), event related optical signal (EROS), and electroencephalograms. Using such techniques, the functions of the different areas of the brain have been identified. The term "area" does not necessarily imply contiguous parts of the brain; these parts may be connected through common nodes. Perhaps a better descriptor is a "network." One current view of the human brain is that it has a modular organization consisting of identifiable component processes that participate in the generation of a cognitive state. The five senses—sight, smell, touch, hearing, and taste—are the gateways to the brain (Fig. 9). Our view of the world is *constructed* by our brain, as it interprets the signals from these five senses coming through the gateways. Although much is known about the details of how the chemical and electrical signals from the five senses are created and pass into the various areas of the brain, these details are not important for our purposes here. The totality of these methods and

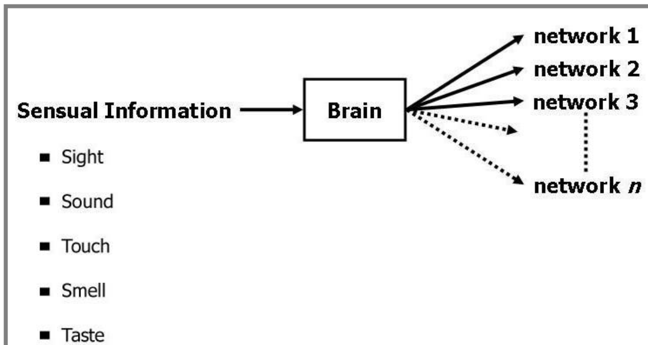

Fig. 9. A representation of how the brain takes input from sensual information and deposits its components in various neural networks.

the results of other experiments produce a representation of the major parts of the brain as well as detailed information on how these are believed to interact with each other.

Our current knowledge produces the following model of how the brain works—how it does what it does. The information input in the brain is *not* stored in a single part of the brain. The brain does *not* store information like an encyclopedia—to be retrieved "as a complete unit on demand." Rather, the data suggest that information is distributed in different networks of neurons, which are the basic elements of brain activity (Fig. 9). Thus, when someone perceives a *skunk*, all the sensual characteristics of the skunk—the hiss, the stripe, the rolling movement, the odor, etc., are stored in different, but appropriate neuron networks (Fig. 10). Retrieving the concept of the skunk from memory corresponds to the interaction of all the specialized networks that contain the skunk-related characteristics, which are then reassembled by the brain into the memory as the skunk concept.

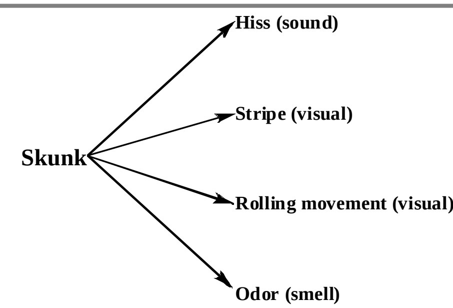

Fig. 10. Some of the sensual information that is associated with the concept "skunk." This information is obtained by the brain and parsed to be deposited in appropriate neural networks.

The human mind creates a number of categories for the kinds of information it stores. About 20 have been identified and there are probably a very large number more (Fig. 11). Notice how the categories listed have strong components associated with the senses, because these are the only signals that reach the brain. So, it appears that his kind of information storage in the brain is genetically encoded since humans have only five senses with which to learn about the world in which they live. From one point of view, the human brain is automatically (genetically hard-wired) a knowledge-seeking entity. The knowledge is that associated with the world in which the brain exists.

KINDS OF CATEGORIES IDENTIFIED FOR KNOWLEDGE ORGANIZATION

- **Fruits and vegetables**
- **Plants**
- **Animals**
- **Body parts**
- **Colors**
- **Numbers**
- **Letters**
- **Nouns**
- **Verbs**
- **Proper names**
- **Faces**
- **Facial expressions**
- **Several different emotions**
- **Several different features of sound**

⋮

etc.

Fig. 11. Kinds of categories identified for knowledge organization.

The distributed information is stored in appropriate networks of neurons that exist in many parts of the brain. The networks are probably interconnected so that the retrieval of the distributed information can start from many places. Many experiments indicate that information is stored in distributed forms, which is then reassembled or reconstructed upon retrieval. It must be noted that "reassembled" and "reconstructed" represent processes that are synonymous with the constructivist mode of learning. Thus, it appears that the sum total of our current knowledge about learning is consonant with the general precepts of constructivism. We "automatically" deconstruct and construct concepts when we learn deeply so it seems logical that teachers should attempt to mimic that process, which is the fundamental basis for the SATL techniques.

CONCLUSION

In this review of the current status of the Systemic Approach to Teaching and Learning (SATL) we have described its relationship to constructivist ideas of learning. Examples of the application of these techniques are detailed for chemistry as is experimental data derived from a study of the efficacy of the method in teaching at the secondary level in Egyptian schools. The modern view of brain function is also linked to constructivist ideas.

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