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EDITORIAL

THE SYSTEMIC APPROACH IN TEACHING AND LEARNING (SATL): 25TH ANNIVERSARY

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The Systemic Approach in 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.

During the last twenty years, the SATL technique has been applied and evaluated in many different knowledge domains at all levels of education (preuniversity, university, adult education), but the major teaching applications have been reported on chemistry topics in secondary and tertiary education. In chemistry, the researchers have conducted a series of successful SATL-oriented experiments, at pre-university, and university levels of education. They have created SATL units in General, Analytical, Aliphatic, Aromatic, Green, and Heterocyclic.

The systemic Approach to Teaching and Learning Chemistry (SATLC) is a teaching strategy founded and developed during the last 25 years. It aims to transform surface learning into deep meaningful learning. This goal can be achieved through the development of systemic thinking using system-oriented learning tasks. These tasks used closed schemes, referred to as systemic diagrams, in which concepts are directly linked to create a closed interconnected conceptual structure. Systemic (Systems) thinking (ST) skills were developed and evaluated in organic chemistry classes with the application of [SATLC] and more precisely by using systemic assessment questions [SAQs]. ST is one of the important learning outcomes of SATLC & a building stone in the preparation of future systemic creative thinkers. Also, ST is one of the crucial demands for Systemic Decision-Making [SDM].

This issue of AJCE published peer-reviewed articles form prominent researchers in the field of SATL in different countries. *[African Journal of Chemical Education—AJCE 13(4), December 2023]*

A 25TH ANNIVERSARY WITH SATL IN CHEMISTRY EDUCATION:
Systemic Approach to Teaching and Learning (SATL), Systemic Assessment (SA) and Systemic Thinking (ST)

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ABSTRACT

About 25 years ago, Fahmy & Lagowski, set up **SATLC** to face; globalization has become a reality we live in with its positive and negative impacts on our lives, the world challenges such as Global climate changes, terrorism, world economic crises, environmental pollution and the widespread of systematization in activities such as tourism, commerce, economy, security, education etc.., So, **SATL** became a must and countries are in an urgent call to prepare their citizens to be able to think systemically and creatively. **SATL** provides inter-relationships between concepts, methodologies, and disciplines. It leads to Systemic Thinking **[ST]** and enhances the quality and quantity of chemistry education. During the last twenty-five years, the SATL technique has been applied and evaluated in many different knowledge domains at all levels of education (pre-university, university, adult education), but the major teaching applications have been reported on chemistry topics in secondary and tertiary education. In chemistry, we have conducted a series of successful SATL-oriented experiments, at pre-university, and university levels of education. We have created SATL units in General, Analytical, Aliphatic, Aromatic, Green, and Heterocyclic Chemistry. These units have been used in Egyptian universities and secondary schools to establish the validity of the SATL approach on an experimental basis. The results indicated that a greater fraction of students was exposed to systemic techniques in the experimental group, achieved at a higher level than the control group taught by conventional linear techniques. The same results have been reached in the experimentation of chemistry units in other countries *(e.g.,* Pakistan, Albania, Slovak*)*. Also**,** Fahmy & Lagowsky used SATL techniques to create a new assessment strategy known as Systemic Assessment [SA] that not only reflects the SATL strategy of instruction but, perhaps, also probes other aspects of student knowledge. SA was used to assess students' achievements after being exposed to SATLC. SA is used to enhance Systemic Thinking [ST]. Also, **ST** is one of the important learning outcomes of SATLC & is very important in the preparation of systemic creative thinkers for Systemic Decision-Making [SDM]. *[African Journal of Chemical Education—AJCE 13(4), December 2023]*

INTRODUCTION

About twenty-five years ago Fahmy and Lagowski [1-6] set up SATL after the spread of globalization in a wide range of human activities. SATL methods have been expressed in chemistry at different educational levels. SATL is a new way of teaching and learning, based on the global idea that nowadays everything is related to everything. They recognized that the basic goal of SATL is the achievement of meaningful understanding by students and suggested that this goal can be attained through the development of systemic thinking, in the context of constructivist and systemic-oriented learning tasks (SATL techniques). Meaningful understanding of chemistry concepts includes the ability of students to link related chemical concepts and construct a chemical representation using chemical information. SATL is also used as a vehicle to engage the students in deep learning which differs from surface learning, which focuses on rote memorization and superficial understanding of concepts and making connections between new and prior knowledge.

The same authors [7] believe that the SATL technique has additional benefits for societies facing globalization issues. As a start, the uses of systemics can help students begin to understand the interrelationships between concepts in a greater context, a point of view, once achieved, that ultimately should prove beneficial to future citizens in the global age. Moreover, if students learn the basis of the systemic process in the context of learning chemistry, we believe that they will doubly benefit; from learning chemistry subject and learning to see all subjects in a greater context.

Unlike concept maps, systemic diagrams are closed systems of the selected concepts with the arrangement of concepts into interacting systems in which all relationships between them are made definitive in front of the learners. Explaining why this difference is crucial, Fahmy and Lagowski noted that such "concept clusters" permit learners to see the domain, subject, or content holistically without missing its parts [4]**.**

Herin, et al 2023 [8] stated the SATL teaching strategy can be considered as a hybrid methodological approach, which combines and utilizes ideas and features of systemic and constructivism adapting them to concept mapping procedures. The primary objective of SATL is the increase of a student's deep understanding of science concepts. They believe that this objective can be achieved through the development of systemic thinking, in the context of constructive educational processes and appropriate, systemically oriented, teaching/learning activities, as those proposed within the SATL strategy. The systemic approach aims to create a dynamically evolving closed system of concepts in a cyclic form. This visual representation of such a conceptual system is named a "*systemic diagram*" which is the main teaching-learning tool used in the SATL-strategy. These diagrams are powerful explanatory tools that can contribute to learning when used in a constructive manner.

Theodoros Vachliotis et al. 2021 [9] stated that in the systemic diagrams, all the stated concepts are interrelated, directly or indirectly, creating a closed conceptual pattern that emphasizes the mutual interactions between concepts. The introduction of new information is accomplished through connection with relevant prior knowledge. The founders of the SATL strategy suggested a specific way for using systemic diagrams as a teaching-learning tool (Fahmy & Lagowski, 1999, 2003) [3, 4]. First, the new subject matter is taught through a traditional linear approach (**LA**) (lectures and presentations). Then, starting from a given initial linear diagram constructed on the basis of relevant prior knowledge, the students with the help of their teachers are encouraged to complete, through sequential steps, a series of structured systemic diagrams (**SD**) required for the section being studied. A progressive systemic interaction of new concepts and their interrelations with the previously taught concepts in the sequential **SD**, from **SD0** (the starting point of teaching the unit) to **SDf** (the end point of teaching the unit) diagrams are clear in front of the students [7, 9].

In SATLC strategy development of a systemic diagram, based on questions asked by the teacher guiding the teaching-learning process. These questions should be answered by students using their relevant prior knowledge and common sense. This approach allows students to participate more actively in the building of the systemic diagrams. The basic differentiation of the SATL strategy compared with a traditional teaching approach is, first, the integration of concept mapping techniques for teaching as well as for assessment of student achievement, and second, the representation and the study of concepts and their interrelationships as a closed and step-by-step growing system (Lagowski; Fahmy [3,4] and Fahmy [7]). A systemic diagram represents a network of connections between concepts that can be meaningful for the student. Such a conceptual whole consists of smaller, conceptually interrelated, subsystems. The study of such a closed systemic involves the application of analysis and synthesis procedures within the defined system, which may lead to the development of systemic thinking skills and, consequently, to enhance understanding [8]. Golmi [10] stated that SATL strategy is the changes in the way of organization of concepts intended to increase the yield and quality of the teaching process besides the role of the teacher as an organizer and the student as an active part in the learning process. SATL is a new approach contrasted to the common approach of the concept map which involves the creation of a hierarchy of concepts [7].

According to Nazir et al [11] systemic approach contradicts the linear method which is currently used in our educational systems. Also stated that teachers can minimize the difficulties in concept building by providing a better perspective related to the basics of the subject. The recently emerged concept-based teaching methodology (SATLC) is a fascinating route to meet this noble endeavor. The SATL method has been discovered to play an essential role, towards the efforts for a better understanding of chemistry concepts. In addition to that, the results reported from the evaluation of the SATL technique have been very promising as far as the improvements in students' academic achievements are concerned.

According to Cardellini et al [12] through the use of a systemic approach, we believe it is possible to teach people in all areas of human activity; economic, political, ethical, and scientific; to practice a more global view of the core science relationships and of the importance of science to such activities. Usually, the classic SATL chemistry concept maps show relationships between disciplinary concepts only; in any case, links with global topics are not graphically recognizable Fahmy [7], in a clear way. Cardellini shows that it is possible to plan a new systemic way of teaching starting from the SATL, pointing out either the connections 'internal' to the discipline or the 'external' ones related to the interactions with the surrounding environment in a global systemic perspective. Also, technical high school students represent a target suitable for SATL strategy because they need to learn chemistry fundamental concepts in a shorter time without losing the connections between them and their role in real situations. John Bradley [13] stated that Fahmy and Lagowski have emphasized the importance of "closed cluster concept maps" in their school curriculum but seem well suited to chemical education for human development in Africa. Also, Bradley added that the three levels of science thought (macro, micro, symbolic), identified by Johnstone and represented by a triangle, may be viewed as a core closed-cluster concept map of the type advocated in the systemic approach to teaching and learning of chemistry.

Maria Ganajova et al. 2022 [14] stated that (SATL) involves an arrangement of concepts/problems into diagrams, which represent how they are linked. The goal of their work is to present the systemic approach in teaching chemistry and provide examples of systemic tasks in terms of this approach on a selected topic from inorganic chemistry, i.e. s-block elements and their compounds. By SATL, systemic tasks in chemistry aim to verify and develop students' ability to determine the relationships and links between reactants and reaction conditions, as well as their ability to write down chemical reactions in the form of chemical equations. The evaluation of teachers' opinions on the pros and cons of the systemic tasks implementation into teaching is presented. Systemic tasks verify and develop students' ability to determine relationships and contexts between reactants and reaction conditions, and skills, which are related to the recording of chemical equations. Teachers see the potential of systemic tasks in deep understanding and development of critical and systemic students' thinking, as opposed to rote learning]. Gulten Sunders 2023 [15] stated that SATL treats concepts and topics in two dimensions and in a spatial arrangement where the presentation of topics and their relationships have a central role.

The main objective here is to build an interactive system in which learners recognize all the relationships between fundamental concepts and topics [16] The difference is that the structure of systemic diagrams manifests in the form of a closed system of concepts, whereas hierarchical concept maps mostly include more limited relationships. All relationships between concepts can thus be shown in systemic diagrams. For example, while we can show the different addition reactions of alkenes in one part of a systemic diagram related to alkenes, in another part, we can show the synthesis of alkenes from alkyl halides. In summary, when we focus on the reactions between organic molecules in systemic diagrams, the diagrams provide much more detailed information compared to concept maps [17]. Presenting concepts in closed-cluster form in systemic diagrams not only enables learners to find detailed information, but also helps them to develop important thinking skills such as decision-making, multidimensional thinking, and forming relationships so that they can organize a conceptual structure [15]. When learners develop such high-level thinking skills, this plays a facilitating role in reaching meaningful understanding. It can be said then that learners can reach a meaningful understanding with SATL

Objectives of SATLC: (7)

1. To change our educational systems from surface to deep learning that prepares our graduates to meet the needs of the global markets besides high skills that enable them to live and act positively in the global age.
2. To face the global challenges that face the world today such as global terrorism, global climate changes etc. That requires preparation of human calibers ready to think systemically and creatively that required for a better and safer world for all.
3. To change our teaching and learning strategy from linearity to systemic which enhances the interconnectedness between learned concepts to build a correct cognitive structure.
4. To face the Global changes of most human activities. Economics, media, security, politics, education, & and health. Are among the human activities that have achieved a global perspective.

5. To enhance the working memory of our student by grabbing their interest by finding ways to connect information that helps with forming and retrieving long-term memory.
6. To enhance our teaching and learning capacity by converting our students into active, creative learners and teachers to act as good facilitators during the learning process.
7. To appreciate the huge contribution of chemistry to human welfare.

Drawbacks of the Current Educational Systems: (7)

Our educational systems suffer from the following drawbacks:

1- Low Performance of the current Curriculum **s**ystem due to the linearity of each component of the curriculum system. To get maximum performance of the systemic curriculum, it is necessary that each of its components should be written systemically and act as a sub-systemic (Fig.1)

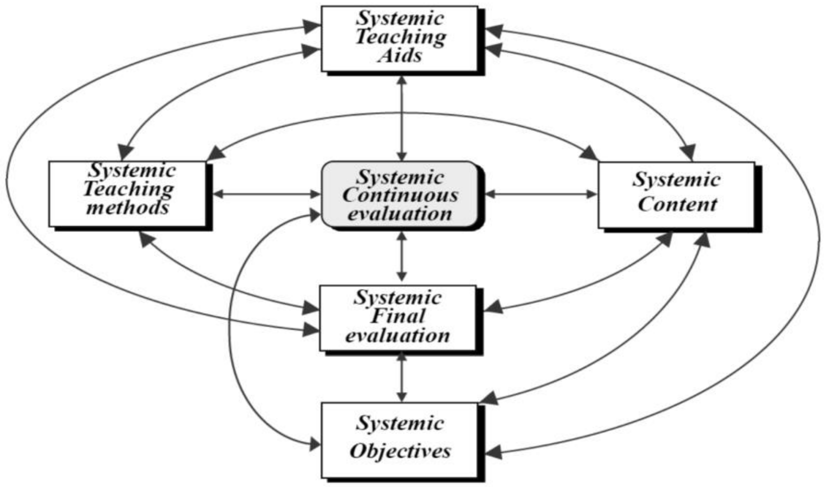

Fig.(1): Systemic curriculum

In the above systemic curriculum diagram, the objectives should be systemic, and each component of the systemic curriculum should be designed systemically.

2. Slight Interaction of the Current Learning Domains:

[Cognitive- Psychomotor, and Affective domains]

CORE IDEA OF SATL

SATL stands on the holistic vision for phenomena where linking different facts and Concepts take place into a dynamic systemic network. This reflects the relationships which settle them into the cognitive structure of the learner and enables him to use it systemically in different situations. It also helps learners to deduce new relations that enrich the operation of teaching and learning from its cognitive, psychomotor and emotional sides. The following diagram illustrates the idea of linear (traditional) and systemic illustrations of concepts.Fig.2a, b [7]

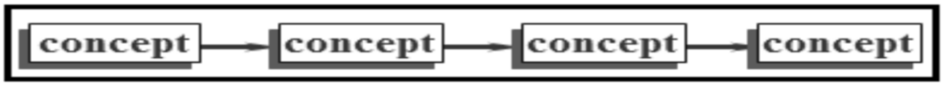

Fig.(2a): Linear (traditional) representation of concepts

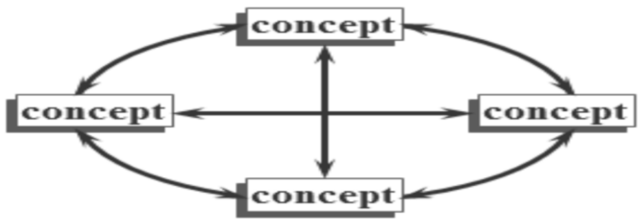

Fig.(2b): Systemic representation of concepts

Systemic Teaching Strategy: [Systemic Constructivist Strategy (SCS)]

In practice, the systemic building strategy was based on the systemic constructivist [SC] of the systemic arrangement of concepts and allows the teacher to build up sequentially a single concept map starting with prerequisite concepts required for the student before he/she starts on a systemic approach to learning. Figure (3) shows this strategy for building the closed cluster of a chemistry concept map **(Systemic**; **SD1-SD5)**.[7]

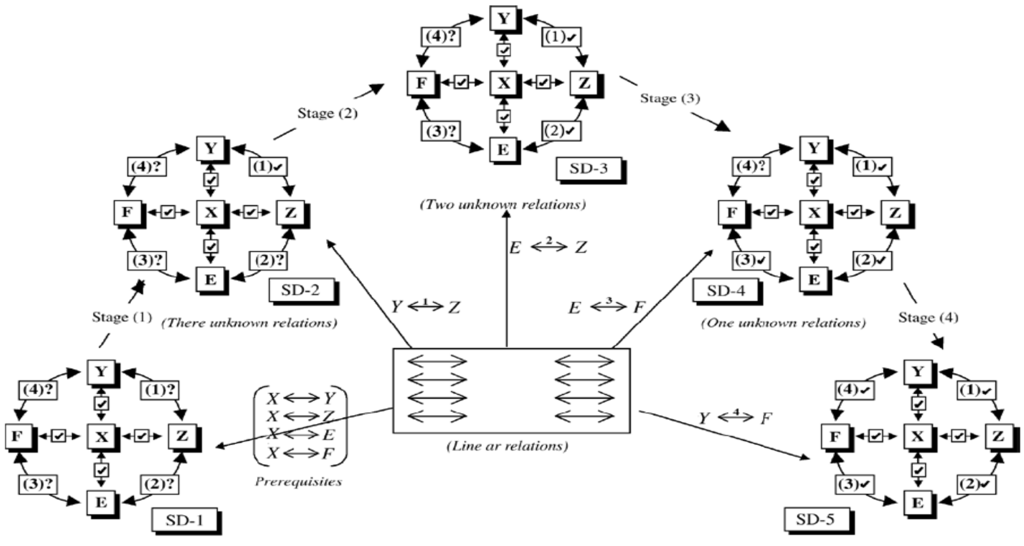

Fig. (3): Systemic teaching strategy.

The above systemic diagrams involved in teaching are similar except that the number of known **(√)** and the unknown relationships **(?)** ones as indicated in Fig.3.

USES OF SATLC- STRATEGY IN REBUILDING UNITS

[SYSTEMIC GENERAL BUILDING STRATEGY]

In the SATL rebuilding strategy of units, we convert the linearly based units in different branches of chemistry to the systemically based units (during teaching) according to the following general strategy [16].

SATL- Strategy for Building Unites in Chemistry:

In continuation to our work on SATL- building strategy of teaching units [16]. We convert the linearly based units in chemistry to systemically based units according to the following general building strategy (Scenario).

Step-1: The systemic aims and the operational objectives for the unit should be defined in the frame of national standards.

Step 2: The prerequisites needed for teaching the unit from previous studies (concepts, facts, reaction types and skills) should be tabulated in a list.

Step 3: Then content analysis of the linearly based unit into concepts, facts, and reaction types, mental and experimental skills.

Step 4: Draw a diagram illustrating linear relations among the concepts of the unit.

Step 5: We modify the linear diagram by putting the sign **(□)** on the already-known relationships between concepts. Then the remaining linear relations are unknown and signed by **(?).**

Step 6: The final linear diagram should be modified to a systemic diagram (**SD0)** by adding unknown relations between the concepts**. SD0** is known as the starting point of teaching the unit.

Step 7: Then the student follows up the scenario of teaching the unit step wisely.

Started by **(SD0)** which has determined the starting point of the unit. The unit ends with a terminal systemic **(SDf)** in which all the relationships between concepts are identified. In going **from SD0 through SDf** he/she will crossover several systemics with known and unknown relationships like **SD1, SD2**, …..etc.

At the end of the teaching scenario of the unit, we can ask the students to build systemics showing the relations between any three, four and/or five concepts (from the **SDf**) via systemic assessment SAQs,s [17-21].

So, the scenario of teaching any course systemically involves the development of a systemic diagram **(SD0)** that has determined the starting point of the course; it incorporates the prerequisite materials. The course ends with a terminal systemic **(SDf)** in which all the relationships between concepts are known. In going from **SD0 through SDf** we crossover several systemics with known and unknown relationships like (**SD1, SD2, etc.)**

I-SATLC-Applications in Egypt

A list of SATLC materials was produced in Egypt, for instance, SATL General Chemistry for secondary schools; SATL Aliphatic, Aromatic, Green Chemistry, Heterocyclic Chemistry, Inorganic Chemistry, and Physical Chemistry for university-level.

SATLC-Secondary Schools I-A:

- Our experiments about the usefulness of SATL to learning Chemistry at the secondary school level were conducted in the Cairo and Giza school districts (2, 6).

I-A-1: SATL-Classification of Elements

- Fifteen SATL-based lessons in inorganic chemistry taught over three weeks were presented to a total of 130 students **(6).** The achievement of these students was then compared with 79 students taught the same material using the standard (linear) method.
- The details of the transformation of the linear approach to the corresponding systemic closed concept cluster were presented.

I-A-1-1: Periodicity of Physical and Chemical Properties of Elements in the Periodic Table (6.7, 22):

1-A-I-1-a: Periodicity of the properties of the elements within the Periods:

Teaching Scenario:

Steps 1-3: Follow the general building strategy from the **first step to third step**. Then move to the following steps.

Step 4: After the students studied the periodicity of physical and chemical properties of elements in periods. They can draw (with the help of their teachers) the following diagram that summarizes the periodicity of the properties **within the horizontal periods** of the periodic table as illustrated in the diagram in (**Figure 4**).

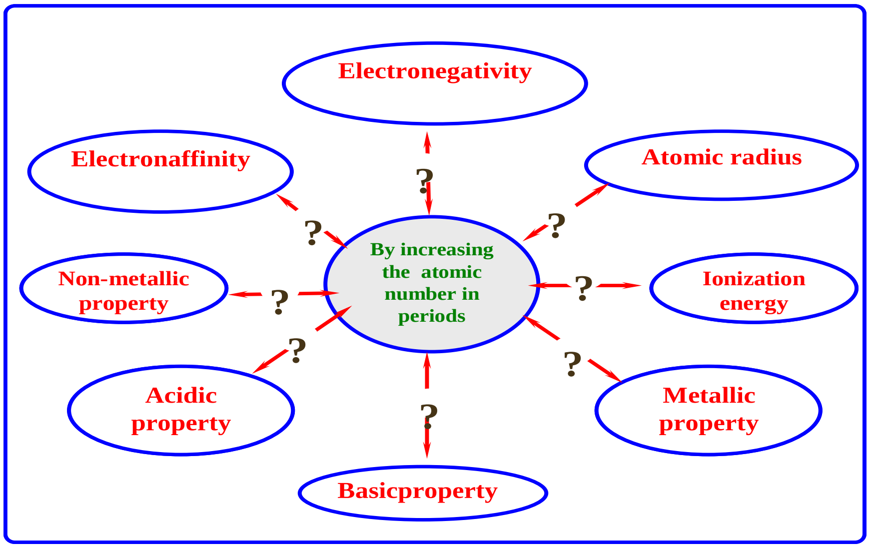

Fig.(4): periodicity of properties of the elements within the periods.

The previous diagram of periods represents linear separated chemical relations between the Atomic number and Atomic radius – Ionization energy - Electron affinity - Electronegativity - Metallic and non-Metallic properties - Basic and Acidic properties.

<u>Step</u> 5: Then the linear Diagram **(Fig.4)** can be transformed by students with the help of their teachers into a systemic diagram **(SD1- P**) which illustrates the periodicity of the properties through the periods systemically **Figure (5).**

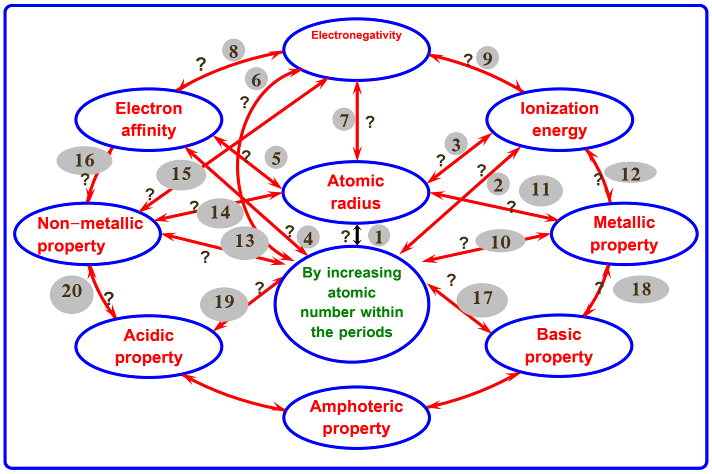

Fig.(5): Systemic diagram (**SD1-P**) for the periodicity of properties of elements in periods

<u>Step</u> 6: The students with the help of their teachers can identify all the unknown relations **(?)** and then modify systemic diagrams **(SD1-P) Figure (5)** to **(SD2-P**) with all known relations for periods **Figure (6)**.

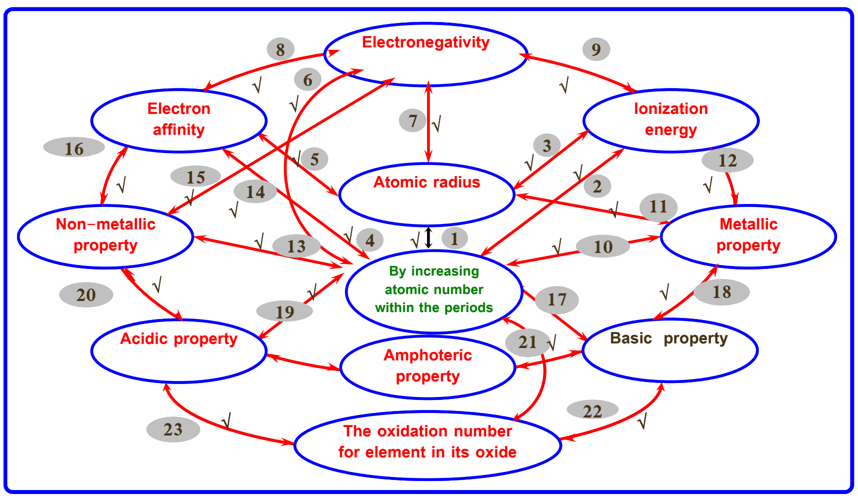

Fig.(6): Systemic Diagram (**SD2-P**) for the periodicity of the Properties for the elements within periods**.**

1-A-I-1-b: Periodicity of the properties of the elements within the Groups:

Step 7: After the students studied the periodicity of physical and chemical properties. They can draw (with the help of their teachers) the following diagram that summarizes the linear periodicity of the properties **within the vertical groups** as illustrated in the linear diagram (**Figure 7).**

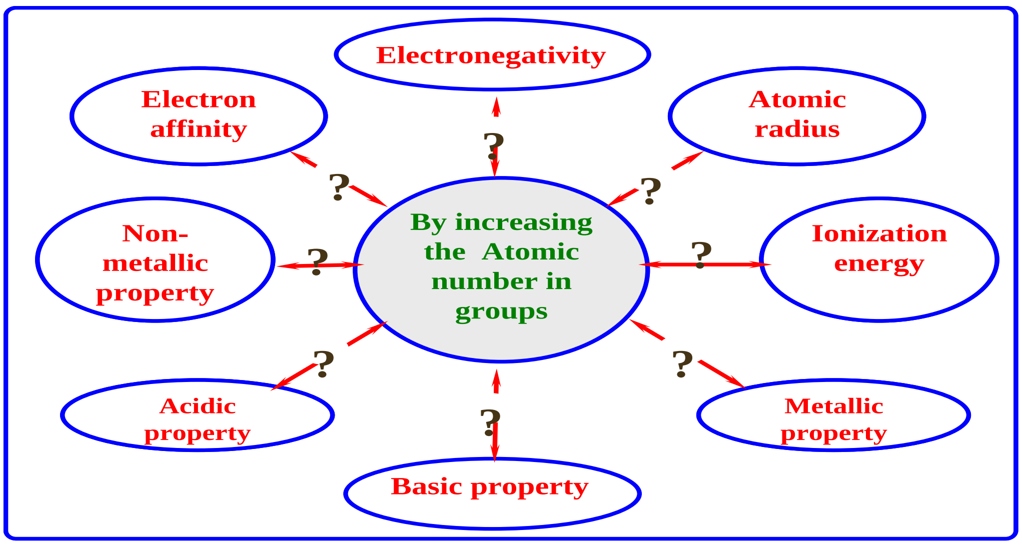

Fig.(7): Periodicity of the properties of the elements within the groups represented in linear separate relations

Step 8: Then the linear Diagram **(Fig. 7)** can be transformed by students with the help of their teachers into a systemic diagram **(SD1-G) Figure (8).**

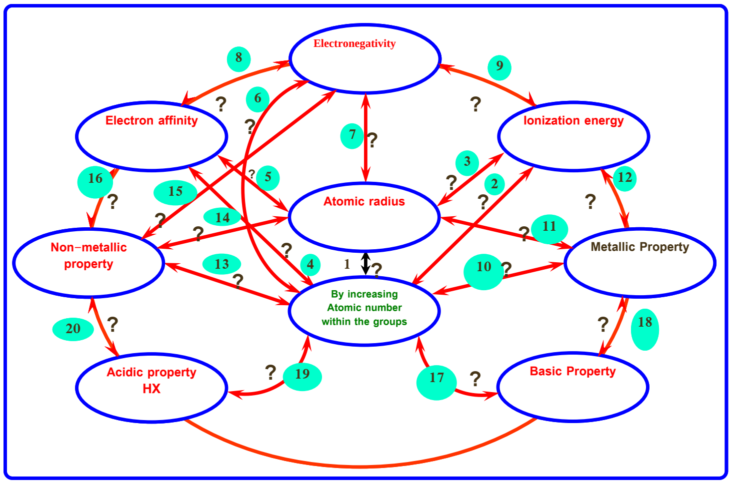

Fig.(8): Systemic Diagram (SD - G) for the periodicity of properties

<u>Step</u> 9: The students with the help of their teachers can identify all the unknown relations **(?)** and then modify systemic diagrams **(SD1-G) Figure (8)** to **(SD2-G)** with all known relations for groups **Figure (9)**,

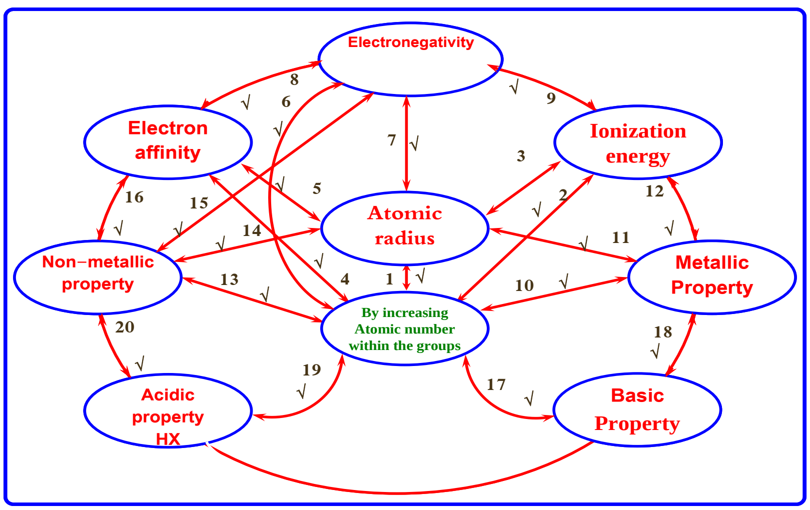

Fig.(9): Systemic Diagram (**SD2 G)** for the periodicity of the properties within groups

I-A-1-2: Systemic Periods and Groups in the periodic Table

I-A-1-2a: Linear and Systemic Periods:

Teaching Scenario:

Step-1: The students by the help of their teachers studied the graduation of the element properties in linear periods of the periodic table from left to right increasing or decreasing. They apply this on the period (2). The linear graduation of the elements properties in the second period starting from Lithium to Neon increasing or decreasing where examined.

Li	**Be**	**B**	**C**	**N**	**O**	**F**	**Ne**

Step-2: Teacher started to explain the meaning of a systemic period as closed system in which each element can be interrelated to the others and the graduation in the properties are studied systemically starting from any element in the period to any other element.

Step-3: Teacher asks the students to transfer the linear period-2 to a systemic period as shown in the **Figure (10).**

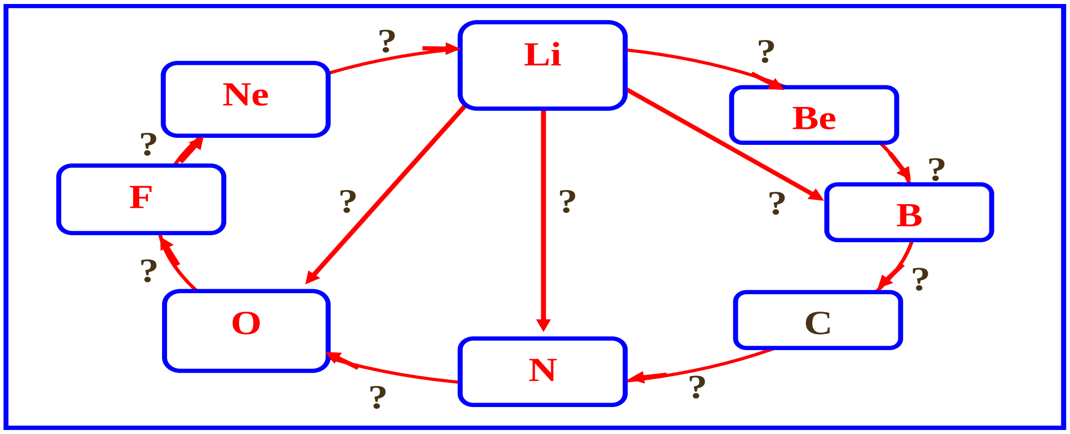

Fig.(10): Systemic period (2)**[SD-P2**]

SD-P2 shows increasing or decreasing in the given property on moving from one element to another through the systemic period.

Step-4: Teacher raises the attention of the students about the main characteristics of the systemic period which differs from the linear period characteristics in the following:

-Find a relation between any element of the period and all the other elements.

- Solve the problem of abnormality in the periodicity of some of the properties. Because it finds the relation between each element and the next element in a certain property till the end of the period.

Step-5: The students' by the help of their teachers indicated the change in the electron affinity in period -2 increases by increasing atomic number with the exception of Beryllium , Nitrogen and Neon as shown in the following table:

Li	Be	B	C	N	O	F	Ne
58.5	**+66**	**-29**	**121**	**+31**	**-142**	**-332**	**+99**
	□			□			□
	(abnormal)			**(abnormal)**			**(abnormal)**

Step-6: Teacher ask students to transfer the electron affinities from the table to the systemic period [**SD-P1] Fig.10**, then put the type of changes in electron affinity between elements (increasing or decreasing) as represented **in Fig 11 –[SD P-2].**

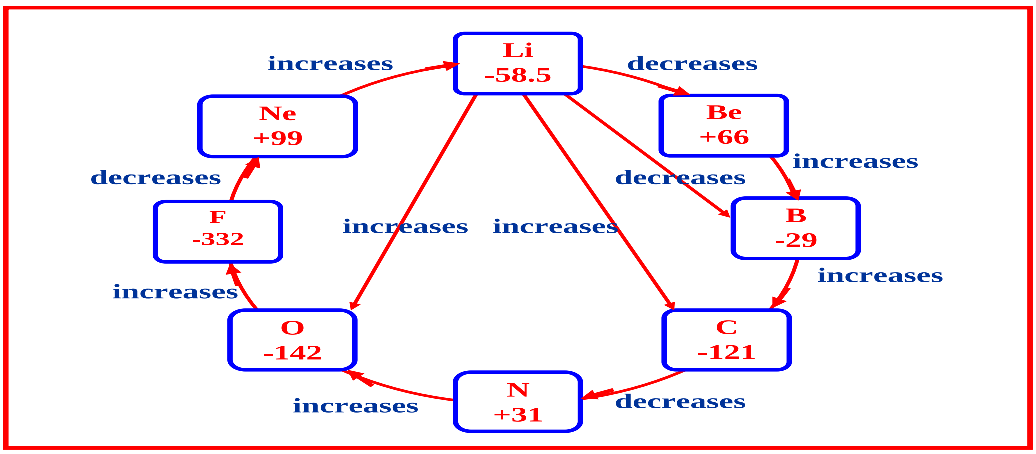

Fig.(11): Periodicity of electron affinity in systemic period (2)[SD-SP2]

-Notice: As the (-ve) value increases the amount of energy released increases.

So, the electron affinity increases**.**

Step-7: Then teacher illustrates the general systemic period **(GS-P)** as shown in **Figure 12.**

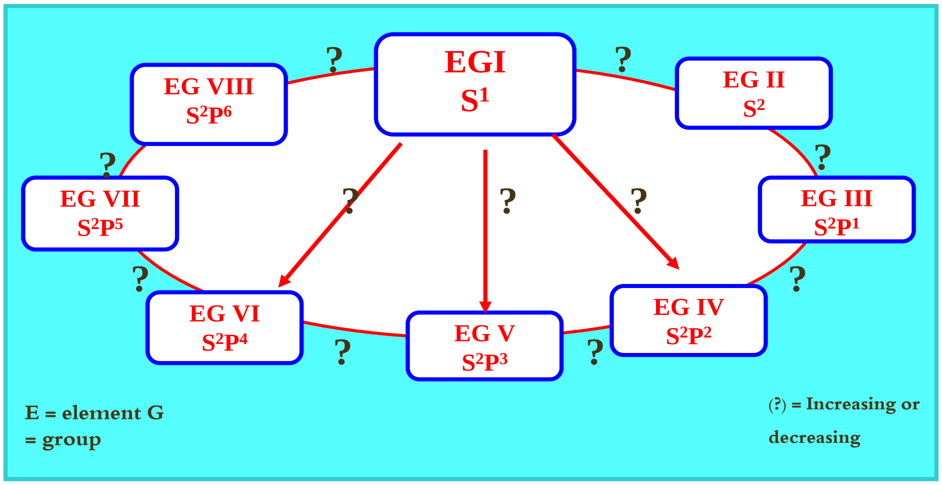

Fig.(12): G-systemic period [GS-P]

Then ask students to use the **(GSP**) to convert other linear periods of the periodic table. By converting those to systemic periods then examine the systemic relations between any two elements in periods.

I-A-1-2b: Linear and Systemic Groups (6, 7, 22)

Step-1: The teacher raises the attention of the students about the main characteristics of the general linear groups includes the graduation of the properties linearity from top to bottom as shown in the following **Figure (13).**

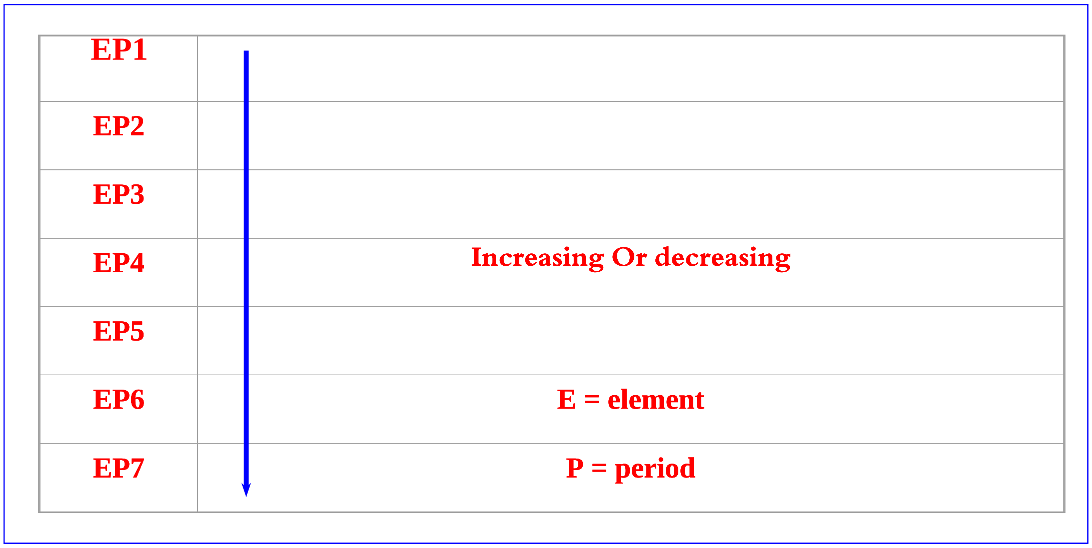

Fig.(13): General Linear Group

Step-2: Teacher started to explain the meaning of a systemic group as closed system in which each element can be interrelated to another and the graduation in the properties are studied systemically starting from any element in the period to any other element.

Step-3: Teacher asks the students to transfer the general linear group figure. **(13)** To systemic general group **[SG-G]** as illustrated in **figure (14).**

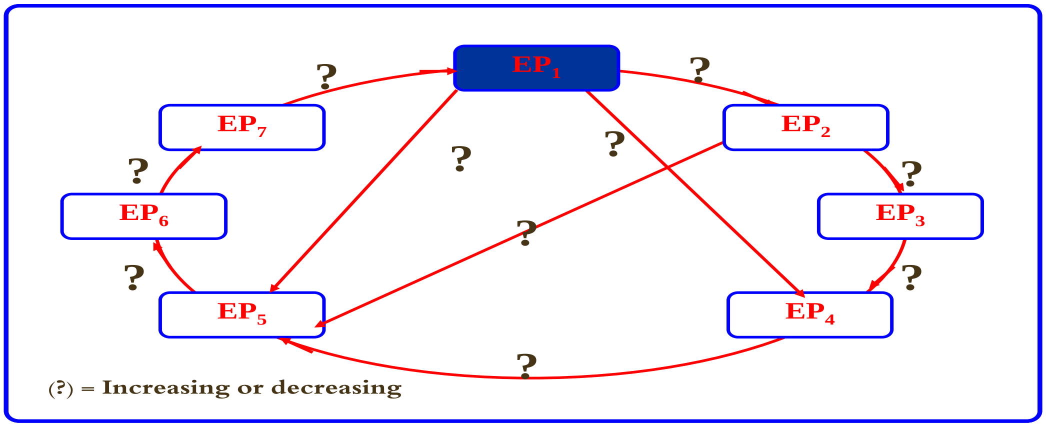

Fig.(14):General Systemic Group [GS-G]

<u>Step</u>-4: The teacher raises the attention of students that in systemic group the graduation in the properties are to be studied systematically. Starting from any element to another. It can be represented by the following systemic (**GS-G) Fig (14).**

<u>Step</u>-5: Teacher asked their students (as an assignment) to transfer the linear groups in the periodic table into Systemic groups by making use of **(SG-G) Fig.(14).**

<u>I-A-1-3: The results of experimentation</u>:

The results of a study of the achievement of a control group, taught linearly vs an experimental group taught by SATL techniques indicate that a greater proportion of students exposed to systemic techniques achieved at a higher level than did the control group. The overall results are summarized in **Figures 15, and 16**

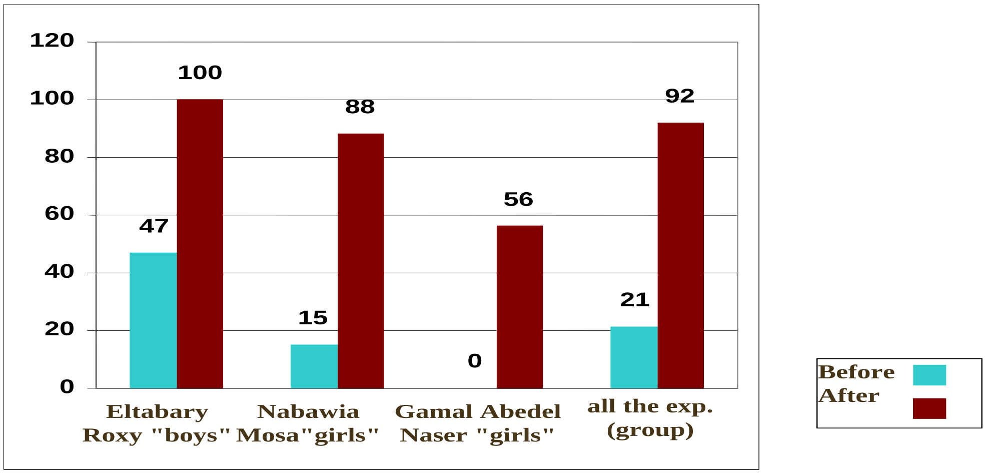

Fig.(15): Percent of students in the experimental groups who succeeded (achieved at a 50% or higher level). The bars indicate a 50% or greater achievement rate before and after the systemic intervention period.

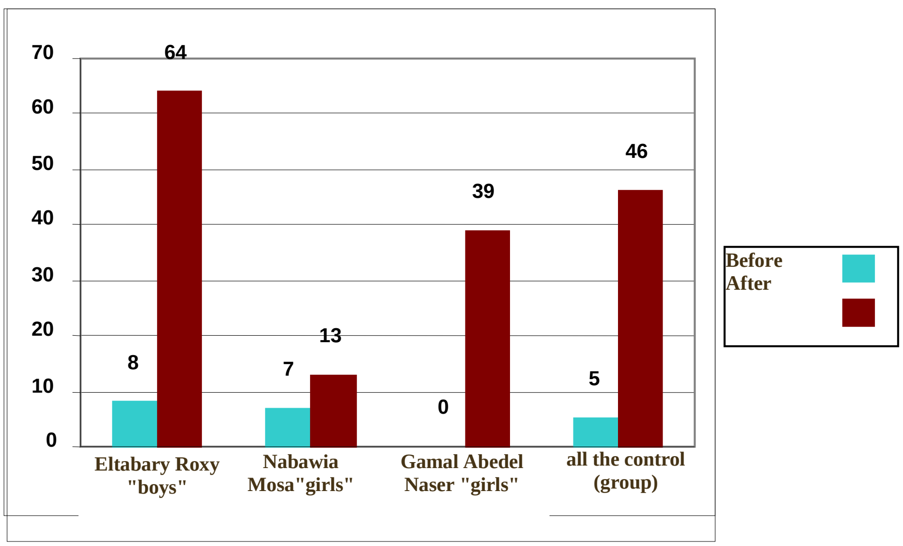

Fig. (16): Percent of students in the control groups who succeeded (achieved at a 50% or higher level).

The results from the pre-university experiments lead to the following conclusions that stem from the qualitative data and from surveys of teachers and students, and anecdotal evidence (**2, 6, and 20**)

a. Implementing the systemic approach for teaching and learning using this unit of general chemistry within the course has no negative effects on the ability of the students to continue their linear study of the remainder of the course by linear approach.
b. Teacher's feedback indicated that the systemic approach seemed to be beneficial when the students in the experimental group returned to learning using the conventional linear approach.

I-B: SATLC – In University Level:

I-B: The Systemic Approach to Teaching and Learning Organic Chemistry (SATLOC): Systemic Strategy for Building Organic Chemistry Units:

I-B-1: [Benzene and Related Compounds] Scenario of Teaching]

In continuation of our work on the uses of SATL- strategy in building chemistry units, especially in aromatic chemistry, herein we will present our work on systemic aromatic chemistry **[17**] via the following scenario of building the above-mentioned unit.

Step 1-3: Follow the general building strategy from **first step to third stip**. Then move to the following steps.

Step 4: After the student studies the synthesis and reactions of benzene. He can draw the following diagram **Fig.1**7 that summarizes synthesis and reactions of benzene.

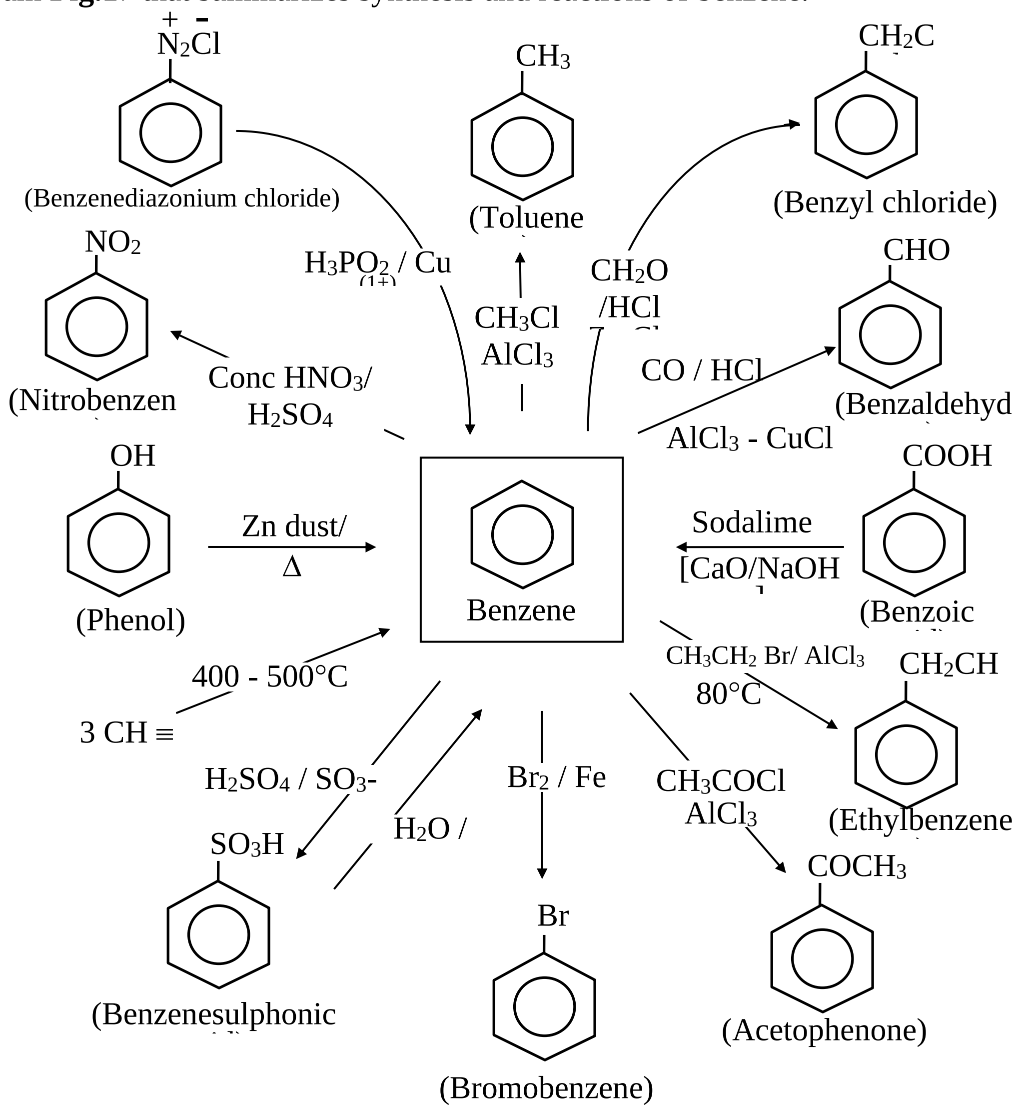

Fig.(17): Linear chemical relationships between benzene and related compounds.

The above diagram shows that all the chemical relations are linear and separated relations.

Step 5: The linear diagram (**Fig. 17**) can be transformed by students via the help of their teachers into a systemic diagram **SDo, Fg.18.** This diagram shows that the individual relationships of the compounds suggested to be synthesized from benzene (alkyl benzenes, nitrobenzene, halo benzenes, phenol, aromatic alcohols benzaldehyde, Acetophenone……….). **Fig. 18** can be systemically interconnected. By adding the unknown chemical relations between them. **SD0** is known as the starting point of teaching the unit (16)

We can illustrate the above chemical relations systemically in the following systemic diagram (**SD0**), **Fig.18**.

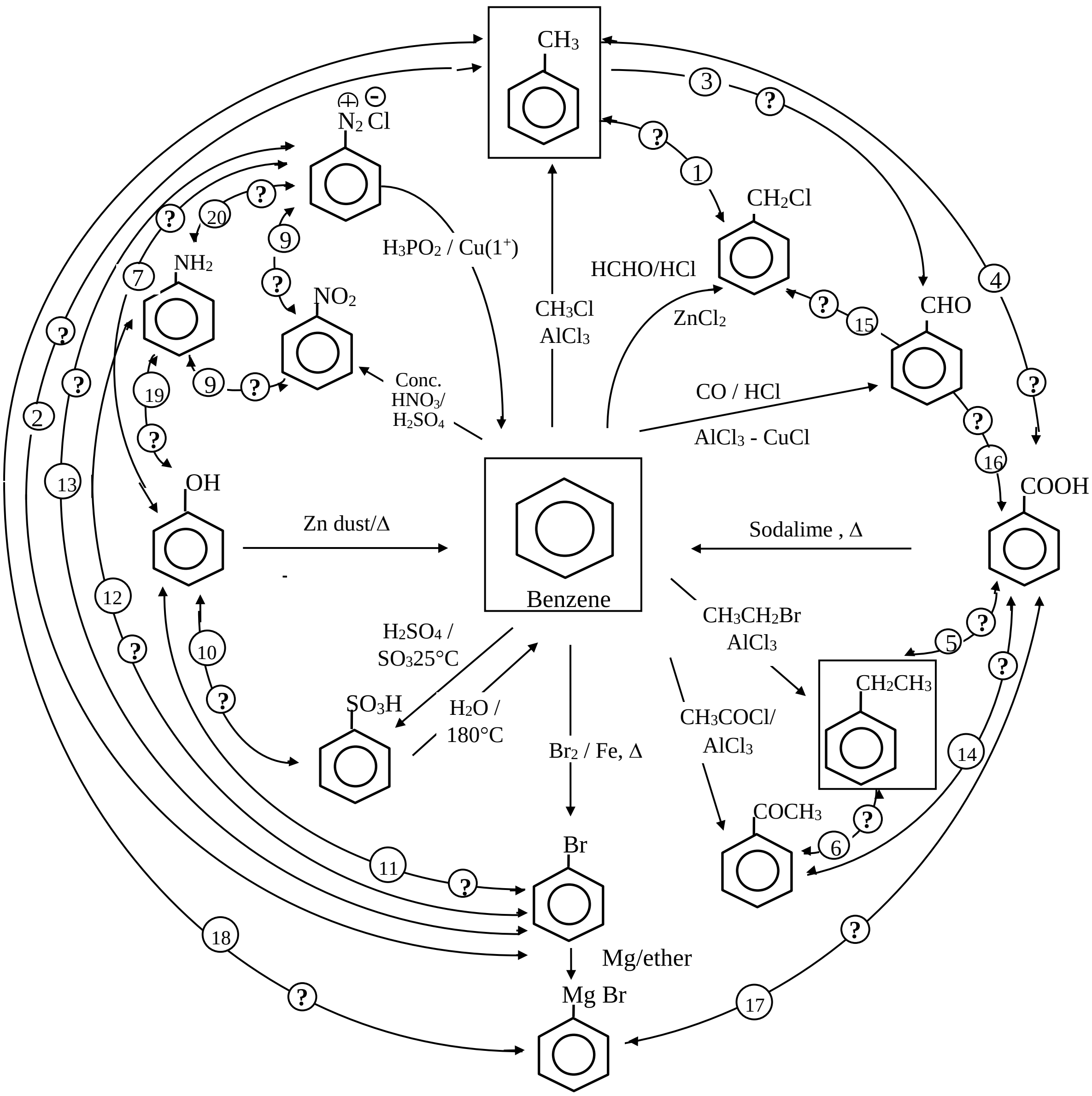
CH3
N2 Cl
H3PO2 / Cu(1+)
HCHO/HCl
ZnCl2
CH3Cl
AlCl3
CH2Cl
CHO
NH2
NO2
Conc. HNO3/ H2SO4
CO / HCl
AlCl3 - CuCl
OH
COOH
Zn dust/Δ
Sodalime , Δ
Benzene
CH3CH2Br AlCl3
H2SO4 / SO325°C
H2O / 180°C
SO3H
CH3COCl/ AlCl3
CH2CH3
Br2 / Fe, Δ
COCH3
Br
Mg/ether
Mg Br

Fig. (18): SD0 - represents some of the major reactions of benzene and benzene derivatives.

The systemic diagram **SD0** shows the unknown chemical relations **1 through to 20** between the aromatic compounds Table 1. These relations will be clarified later during the study of the unit,

Table (1):

No.	Chemical Relations		No.	Chemical Relations	
1	Toluene and benzyl chloride	?	12	Bromobenzene and aniline	?
2	Toluene and bromobenzene	?	13	Bromobenzene and benzene-	?
3	Toluene and benzaldehyde	?		diazonium chloride	
4	Toluene and benzoic acid	?	14	Acetophenone and benzoic acid	?
5	Ethylbenzene and benzoic acid	?	15	Benzyl chloride and benzaldehyde	?
6	Acetophenone and ethyl benzene	?	16	Benzaldehyde and benzoic acid	?
7	Phenol and benzenediazonium	?	17	Phenyl magnesium bromide and	?
	Chloride.	?		benzoic acid	
8	Nitrobenzene and benzene-		18	Phenyl magnesium bromide and	?
	diazonium chloride.	?		toluene	
9	Nitrobenzene and aniline.	?	19	Phenol and aniline	?
10	Phenol and benzenesulphonic.		20	Aniline and benzenediazonium	
	Acid.	?		chloride	
11	Bromobenzene and phenol.				?
					?

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<u>Step </u>6: <u>[Change of SD0 to SD1]</u> After all possible synthetic routes and reactions of Alkyl benzenes are discussed in the classroom and after the recognition of various chemical relations the systemic diagram **SD0** can be improved by students into another systemic diagram **SD1-Fig.19** by adding chemical relations (**<u>1 through 6, and 18)</u>**.

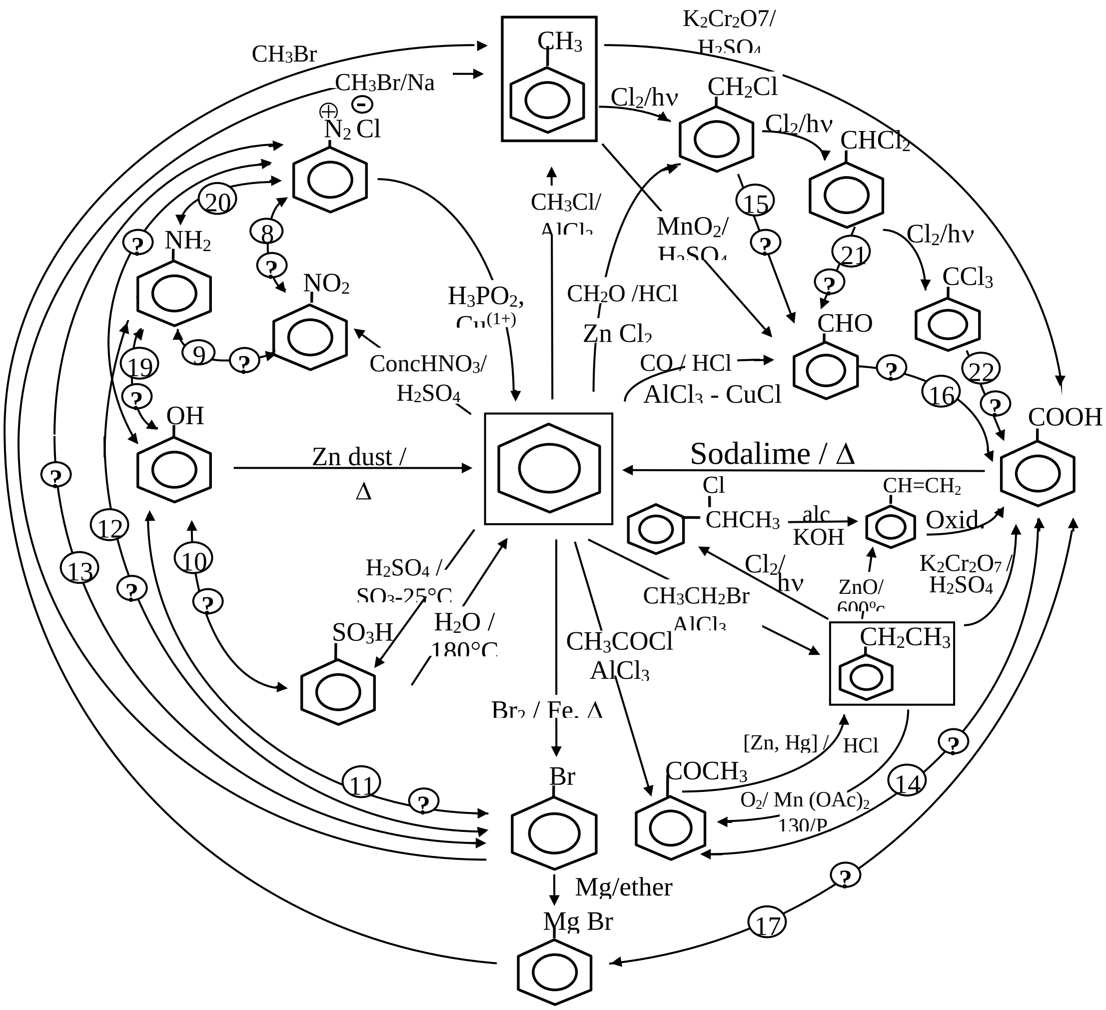


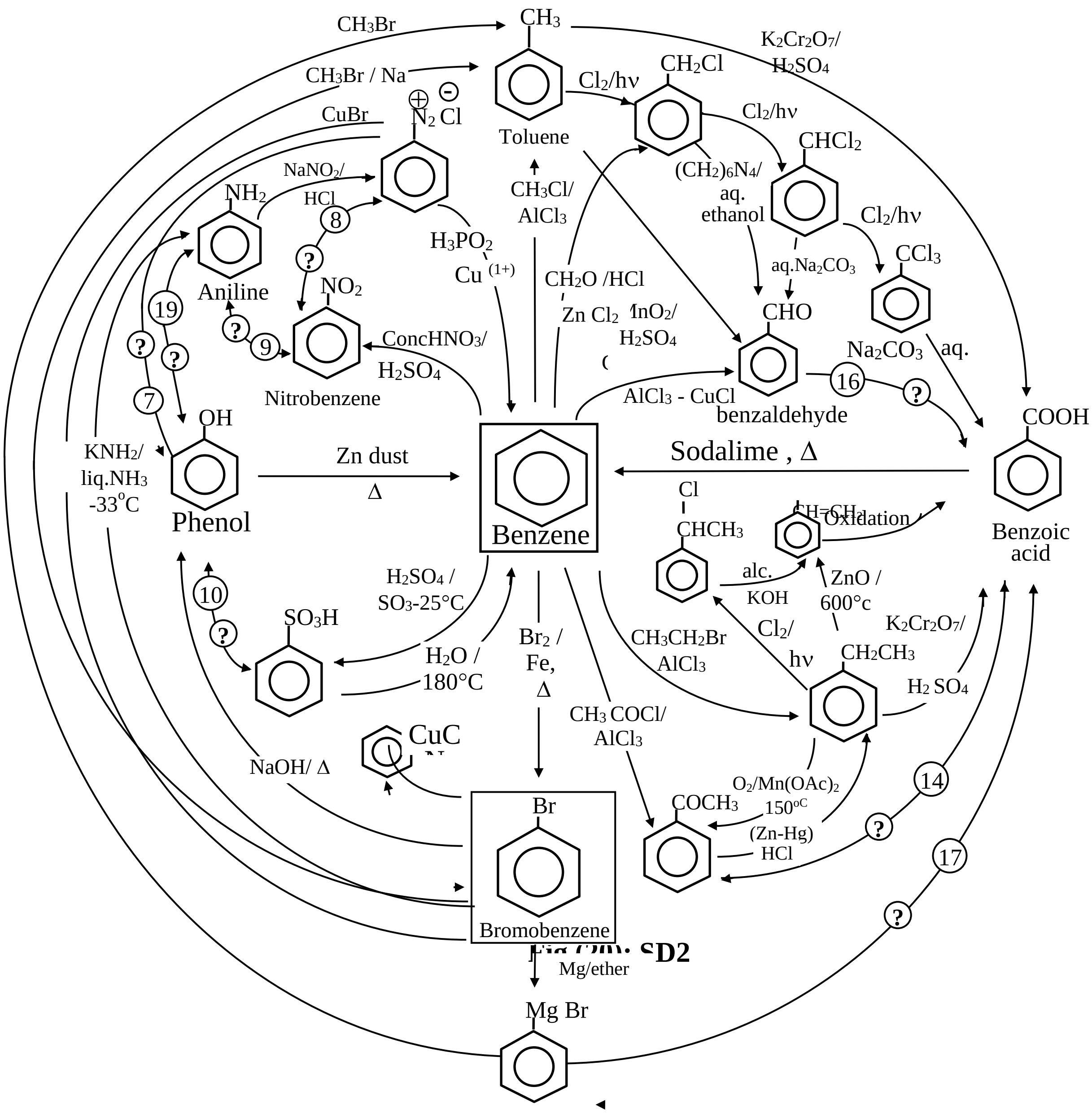
Fig.(19): SD1

Step7: **[Change of SD1 to SD2]**: After progress in teaching the unit via the gilded classroom discussions about the synthesis and reactions of halogen derivatives of aromatic hydrocarbons the systemic diagram **SD1** can be improved by students into systemic diagram **(SD2, Fig.20)** by adding the following defined chemical relations **(cf. Table 2).**

Table (2):

No.	Chemical relations	
11	Bromobenzene to phenol [NaOH, heat]	✓
12	Bromobenzene to aniline [KNH_2/liq. NH_3]	✓
13	Benzenediazonium chloride to bromobenzene [CuBr]	✓
15	Benzyl chloride to benzaldehyde [$(CH_2)_6N_4$/aq.alc.]	✓
20	Aniline to benzenediazonium chloride ($NaNO_2$/HCl)	✓
21	Benzal chloride to benzaldehyde [aq. Na_2CO_3]	✓
22	Benzotrichloride to benzoic acid [i)aq.Na_2CO_3, ii)HCl]	

But we still have unknown chemical relations (**7-10, 14, 16, 17, and 19).** These relations will be defined during our study of the rest of the aromatic chemistry unit.


CH3Br
CH3
CH3Br / Na
Toluene
CH2Cl
Cl2/hν
K2Cr2O7/
H2SO4
CuBr
N2 Cl
Cl2/hν
CHCl2
NaNO2/
HCl
8
NH2
Aniline
CH3Cl/
AlCl3
(CH2)6N4/
aq.
ethanol
Cl2/hν
H3PO2
Cu (1+)
?
CCl3
aq.Na2CO3
NO2
19
?
9
Nitrobenzene
ConcHNO3/
H2SO4
CH2O /HCl
Zn Cl2
H2SO4
CHO
Na2CO3
aq.
7
AlCl3 - CuCl
benzaldehyde
16
?
COOH
OH
KNH2/
liq.NH3
-33°C
Phenol
Zn dust
Δ
Benzene
Sodalime , Δ
Benzoic
acid
Cl
CHCH3
Oxidation
alc.
KOH
ZnO /
600°c
10
SO3H
H2SO4 /
SO3-25°C
H2O /
180°C
Br2 /
Fe,
Δ
CH3CH2Br
AlCl3
Cl2/
hν
CH2CH3
K2Cr2O7/
H2 SO4
CH3 COCl/
AlCl3
NaOH/ Δ
Br
COCH3
O2/Mn(OAc)2
150oC
(Zn-Hg)
HCl
14
17
Bromobenzene
SD2
Mg/ether
Mg Br

<u>Step.8: [Change of SD2 to SD3]</u>: After studying the **<u>synthesis and reactions of benzenesulphonic acids</u>** the student can improve **(SD2 to (SD3**, **Fig.21**) by adding the reactions of sulphonic acids with NaOH **(relation 10),** and KSH, KCN, $NaNH_2$.But we still have unknown chemical relations **<u>(7-9, 14, 16, 17, and 19).</u>**

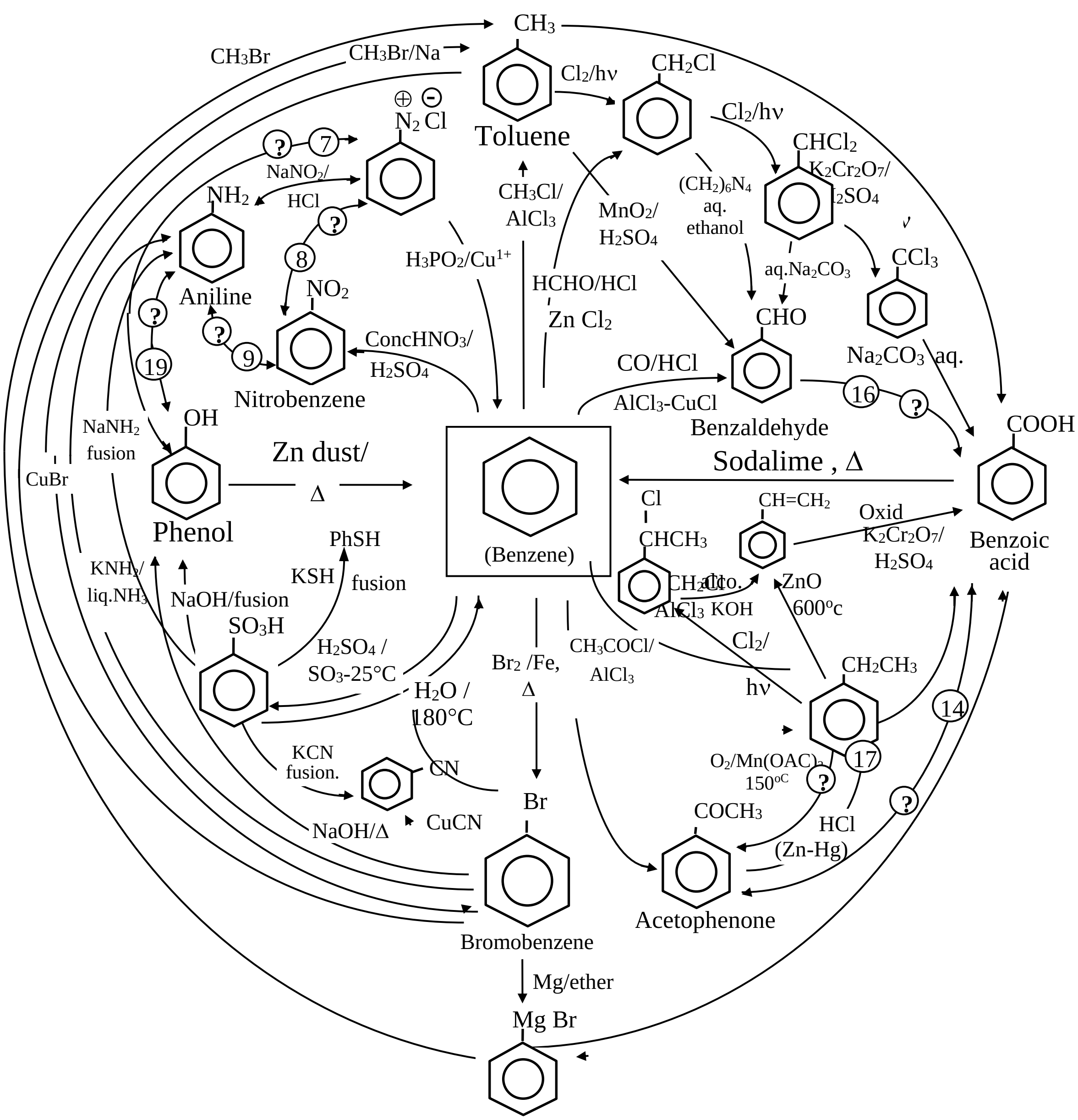


Fig.(21): SD3

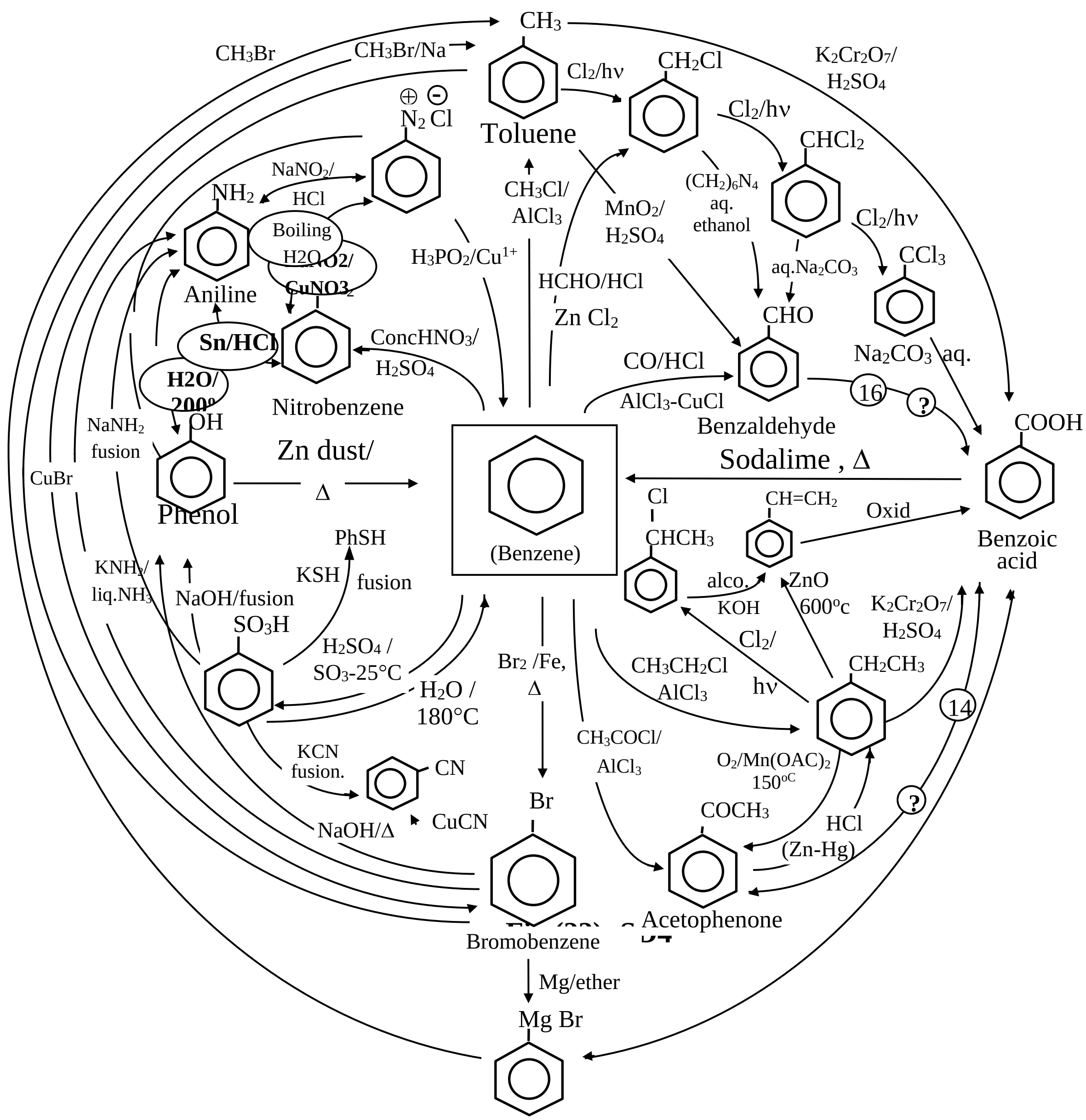
<u>Step</u> 9: <u>[Change of SD3 to SD4]</u>:

After studying the **synthesis and chemical reactions of aromatic nitro - compounds, diazonium salts and aniline** the student can change the systemic diagram **(SD3) to (SD4**, **Fig.22**) by adding the following chemical relations **Table (3):**

Table (3)

NO.	Chemical relations	
8	Benzenediazonium chloride to nitrobenzene ($NaNO_2$ / Cu NO_2)	✓
7	Benzenediazonium chloride to phenol (Boiling water)	✓
9	Nitrobenzene to aniline (reduction Sn / HCl)	✓
19	Aniline to phenol (H_2O, 200^o).	✓

But we still have the following unknown chemical relations. **[14, 16, 17].** These relations will be defined later during our study of the rest of the Aromatic chemistry unit.


CH3
CH3Br
CH3Br/Na
Cl2/hν
CH2Cl
K2Cr2O7/
H2SO4
N2 Cl
Toluene
Cl2/hν
CHCl2
NaNO2/
HCl
NH2
Boiling
H2O
CH3Cl/
AlCl3
MnO2/
H2SO4
(CH2)6N4
aq.
ethanol
Cl2/hν
H3PO2/Cu1+
CCl3
Aniline
HCHO/HCl
Zn Cl2
aq.Na2CO3
CHO
Sn/HCl
ConcHNO3/
H2SO4
CO/HCl
Na2CO3 aq.
H2O/
200°
OH
Nitrobenzene
AlCl3-CuCl
16
?
NaNH2
fusion
Benzaldehyde
COOH
Zn dust/
Δ
Sodalime , Δ
CuBr
Phenol
Cl
CH=CH2
Oxid
PhSH
CHCH3
Benzoic
acid
KNH2/
liq.NH3
KSH
fusion
(Benzene)
NaOH/fusion
alco.
KOH
ZnO
600°c
K2Cr2O7/
H2SO4
SO3H
H2SO4 /
SO3-25°C
Br2 /Fe,
Δ
Cl2/
hν
CH3CH2Cl
AlCl3
CH2CH3
H2O /
180°C
14
KCN
fusion.
CN
CH3COCl/
AlCl3
O2/Mn(OAC)2
150°C
NaOH/Δ
CuCN
Br
COCH3
?
HCl
(Zn-Hg)
Acetophenone
Bromobenzene
Mg/ether
Mg Br

<u>Step10</u>: **<u>[Change of SD4 to SDf]</u>** After studying of **<u>synthesis and chemical reactions of aromatic aldehydes, ketones and acids</u>** the student can modify the systemic diagram **(SD4) to (SDF, Fig.23)** by adding the following chemical relations.

No	Chemical relation	
14	Acetophenone to benzoic acid ($KMnO_4$)	√
16	Benzaldehyde to benzoic acid ($KMnO_4$)	√
17	Phenyl magnesium bromide to benzoic acid (CO_2, H_2O)	√

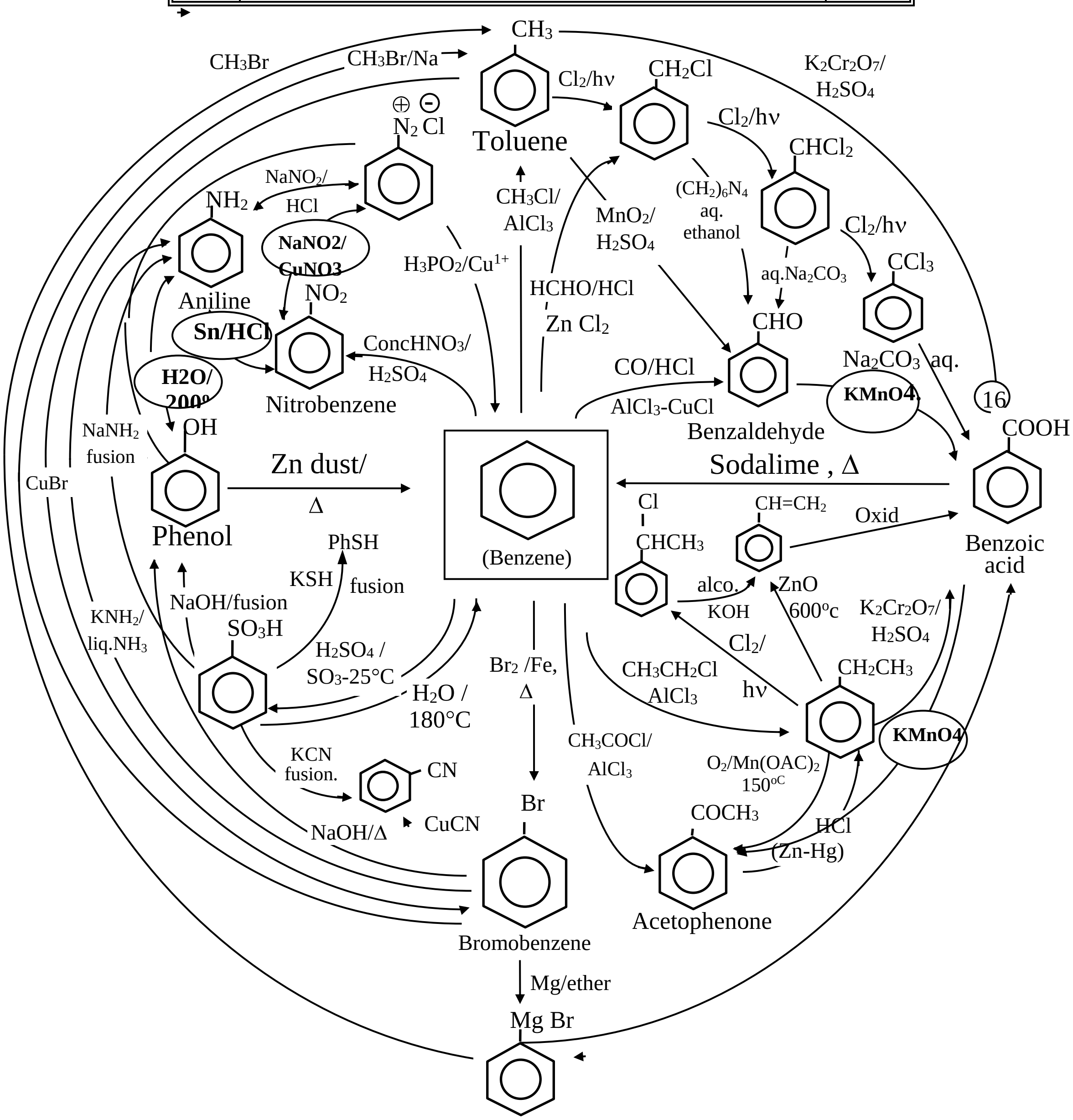


Fig.23: SDf

In the **(SDF)** all chemical relations between benzene and its related compounds were clarified and we reach the end point of teaching the unit. At this point, new ideas and connections begin to arise in students' minds in a systemic pattern. This will open the door for new approaches towards synthetic organic chemistry. Also; we can assess the student achievements in aromatic chemistry after each stage of learning the unit via Systemic Assessment Questions **[SAQ, s]** on the systemic diagrams from **SD0** to **SDF** (**18-23-**).

I-B-2: Aliphatic Chemistry [Aliphatic Hydrocarbons]

We present here the results of a study of the efficacy of systemic methods applied to the usual first-semester content of the second-year organic chemistry course (16 lectures, 32 hours) at Zagazeg University [6,7]

Scenario of Teaching:

In continuation of our work on the uses of SATL- strategy in building chemistry units, especially in aromatic chemistry, herein we will present our work on systemic aliphatic hydrocarbons via the following scenario of building the above-mentioned unit.

Steps 1-3: Follow the general building strategy from the **first step to the third step**. Then move to the following steps.

<u>Step</u> 4: After the student studied the synthesis and reactions of Alkanes. He can draw the following diagram **Fig.24** which summarizes the synthesis and reactions of Alkanes.

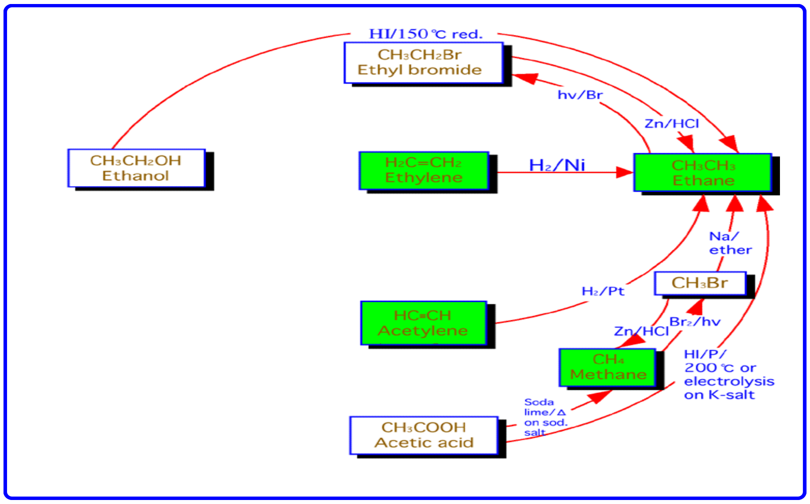


Fig. (24): Linear diagram that represents summarizes the synthesis and reactions of Alkanes.

The linear version of teaching this material was presented to a group of students that were the control group in our study. The systemic version was taught to another group of students defined as the experimental group.

<u>Step</u>-5: The linear diagram (**Fig.24**) can be transformed by students via the help of their teachers into a systemic diagram **SDo, Fig.25.** This diagram shows that the individual relationships of the compounds suggested to be synthesized from Methane which are (Ethane- Ethylene-Acetylene Methyl bromide -Ethyl bromide-Ethanol-Acetic acid).

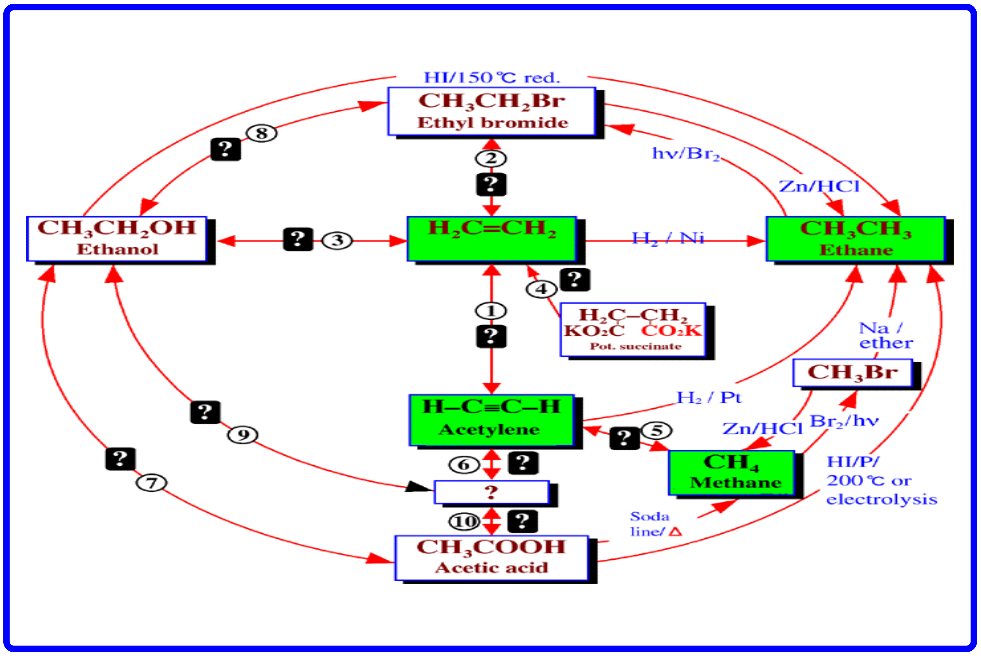


Fig.(25): Systemic diagram (SD0) that represents some of the major chemistries of alkanes.

In the systemic diagram **SD0** some chemical relationships are defined whereas others are undefined (to be learned). These undefined relationships are developed systematically.

Step-6: After using the diagram **SD0** shown in **Fig. 25** as the basis for the study of the synthesis and reactions of alkenes, and alkynes, the students can modify this systemic diagram **(SD0 in Fig. 25)** to accommodate other chemistries of hydrocarbons as shown in **(SD1), Fig. 26.**

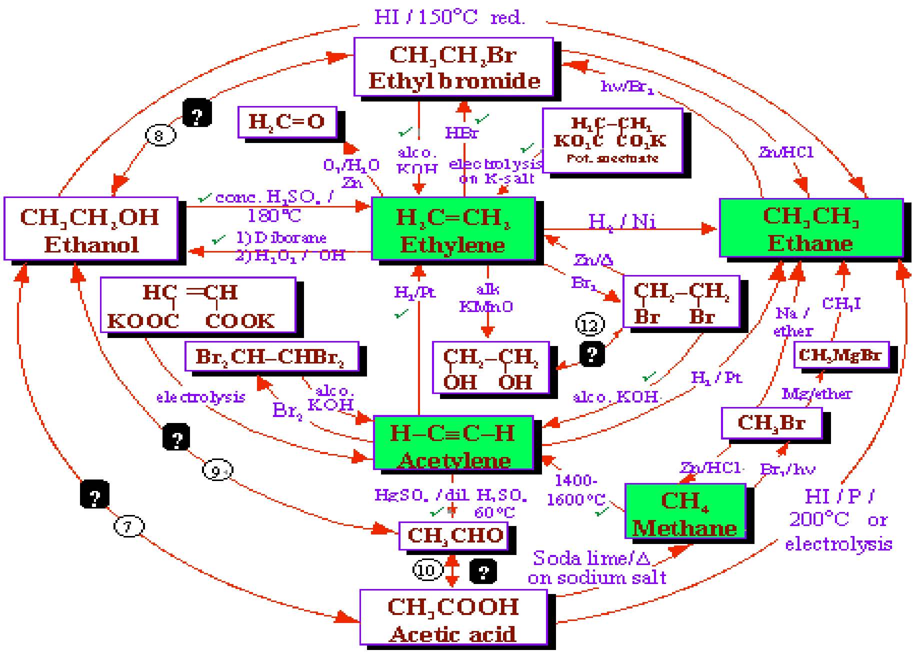


Fig. (26): The systemic Diagram (SD 1) illustrates the relationship between the hydrocarbons and derived compounds.

The systemic diagram (SD-1) shown in Figure (25) can be used to accommodate the chemistries of ethyl bromide and ethanol yielding a new systemic diagrams **(SD27, SD28).**

The systemic diagrams developed were used as the basis for teaching organic chemistry courses to the experimental group at (Zagazeg University Egypt). The experiment was conducted within the Banha branch, Faculty of Science, Department of Chemistry with second-year students. The experiment involved (41) students in the control group, which was taught using the classical (linear) approach; (122) students formed the experimental group, which was taught using SATL methods illustrated in the systemic diagrams shown in Figures (SD0) through (SD3).- The success of the systemic approach to teaching organic chemistry was established by using an experimental group, which was taught systemically, and a control group, which was taught in the classical linear manner.

- **Figures (29) and (30)** show the final data in terms of student achievement. These data indicate a marked difference between the control and experimental groups.

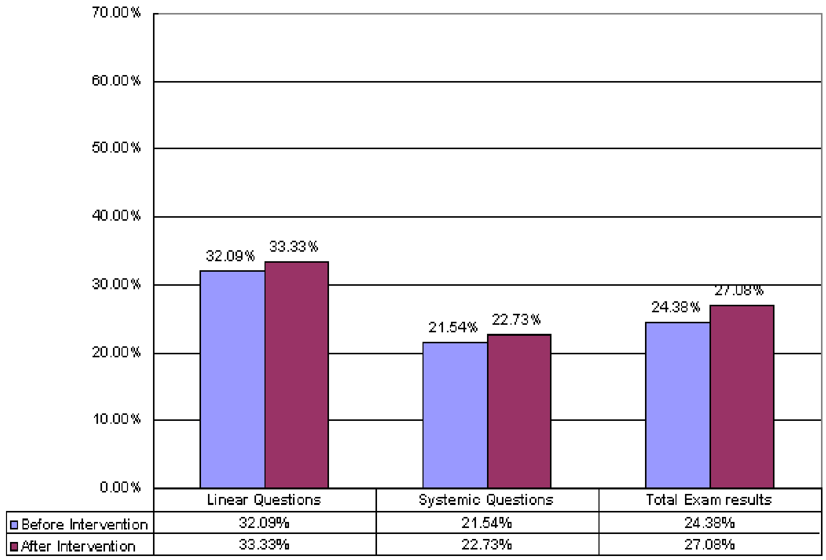


Fig. (29): Average scores for control groups before and after intervention.

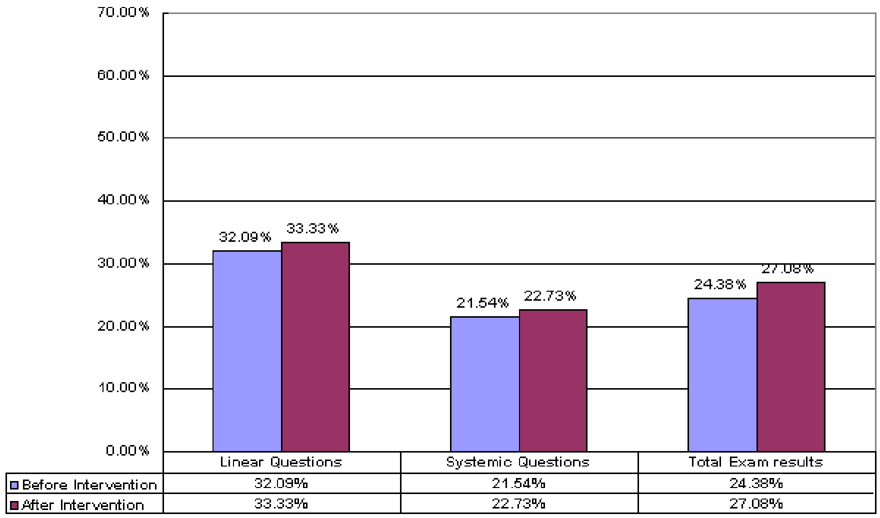


Fig.(30): Average scores for the experimental group before and after the intervention.

-SATLOC improves the students' ability to view OC from a more global perspective.

-SATLOC increases students' ability to learn subject matter in a greater context.

- SATLOC helps the students to develop their mental framework at higher-level Cognitive processes (application, analysis, and synthesis).

II-SYSTEMIC ASSESSMENT [SA

Systemic assessment [SA] in chemistry is a new innovative way of evaluating students' understanding of chemistry concepts and their interrelationships. It is based on the systemic approach to teaching and learning (SATL), which uses systemic diagrams and systemic assessment questions (SAQ,s) to help students learn chemistry in a meaningful and holistic way. SAQs,s are different from traditional linear questions, as they require students to analyze, synthesize, evaluate, and correlate between concepts in a systemic way Fahmy [21]. According to Fahmy & Laowski [18-21] SAQ,s can be of various types, Systemic multiple choice[SMCQs,s].Systemic true false [STFQ,s], Systemic Maching questions [SMQ,s], Systemic synthesis questions[SSynQ,s], Systemic analysis questions[SAnQ,s] and Systemic sequencing questions [SCQs].

These types of questions can be used to assess students' learning outcomes in different domains of chemistry, such as organic chemistry, inorganic chemistry, physical chemistry, and general chemistry, at secondary and tertiary levels [18-21]. Systemic assessment has been shown to be an effective tool for improving students' academic achievements, increasing equity of learning outcomes, and enhancing students' higher-order thinking skills. The SAQ scheme was found to be a valuable strategy for assessing meaningful understanding, as well as systems thinking in organic chemistry. A significant association was observed between students' performance on SAQs and on objective items designed for assessing meaningful understanding of organic chemistry concepts. This association indicates that the students' systems thinking level developed in organic chemistry is strongly related to a deeper understanding of the relevant science concepts [22,23]. To solve SAQs students should consider several concepts at once, as well as their relationships with one another. So that they can apply them to a new problematic situation.SAQs access students' ability to correlate between different concepts, and also to discover the new relationships between them.[24] A single question covers a wide range of concepts in the selected course topic, *e.g.*, several classes of organic compounds: alkanes, alkenes, alkynes, alkyl halides, alcohols, aldehydes and carboxylic acids [20,24]. Recent studies indicated that Systemic Assessment Questions [SAQs] are valid and reliable evaluation tools for 11th-grade high school students. SAQs consider several concepts at once applying them in a new situation which requires the synthesis of a comprehensive answer [23].

II-1.1. Why Systemic Assessment? (7)

Systemic assessment (SA) has the following advantages: (i.) measures the cognitive structure from the quantitative through the qualitative (domains); (ii). assesses student's higher-order thinking skills where they are required to analyze, synthesize, and evaluate; (iii). it measures the student's ability to correlate between concepts; (iv). enables the students to discover new relationships among concepts; (v). gives the students rapid feedback during the term about how well they understand the course material; (vi). assesses the students in a wide range of concepts in the course units (learning outcomes, ILOs); (vii) develops the ability of students to think systemically, critically, and creatively, and to solve problems; (viii). very easily scored.

II-1-2: The Role of Systemic Assessment in the Systemic Curriculum: (7)

To have a systemic curriculum the following should be done:

1- The objectives should be systemic.

2- The content should be arranged systemically as shown in the **(SD0)**.

3- The teaching method should be systemic and start by systemic **(SD0)** and end by terminal systemic **(SDf),** passing by Intermediate systemics **(SD1 and SD2), (Fig. 2).**

4- The multimedia should be systemic, helping the teacher to teach the unit systemically.

5- All the above curriculum components should interact and be in harmony, affecting one another into one systemic unit, then the assessment comes stepwise from the beginning of the unit teaching till to the end.

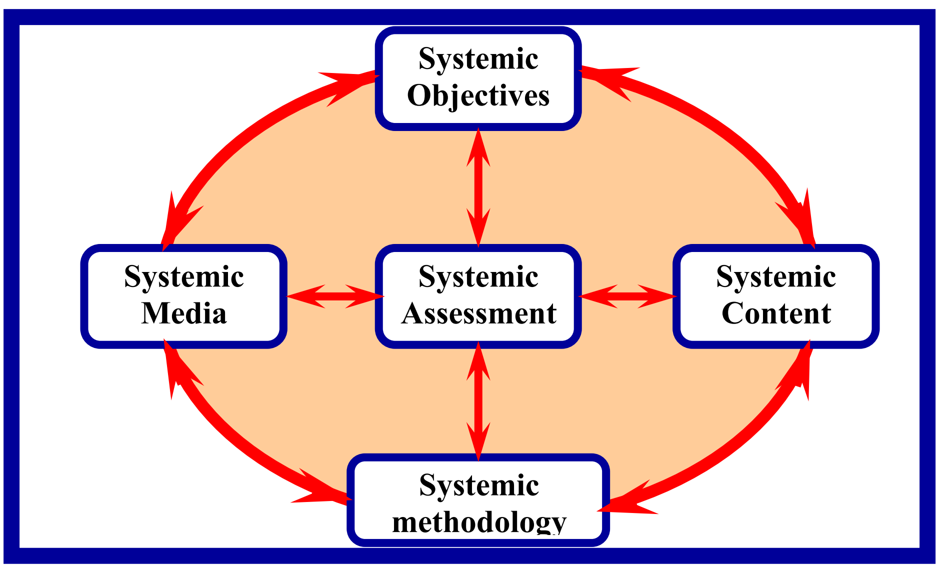


Fig. (31): Systemic curriculum:

Systemic assessment is the key component of the systemic curriculum. As shown in **Fig. 31.** It is used during the course to monitor the student's progress **(formative)** and at the end of the course to monitor the progress student's Cognitive Structure (**summative**).

II-1-3: Purpose of Systemic Assessment:

The main aim of SA is to enhance, support and improve both teaching and learning processes via:

1. Help teachers use evidence of student learning to assess student achievement against the goals and standards of the courses and programs.
2. Help teachers to improve their teaching performance.
3. Enable students to give feedback during their study of any course materials.
4. Help students make maximum connections between Chemistry concepts, compounds, and reactions.
5. Enable students to achieve the highest standards they are able.

II-1-4: Types of Systemic assessment Questions :

SAQs,s could have several chaps, depending on what type of SAQ you need. Fahmy and Lagowski (18-21) have presented the following types of SAQs: systemic multiple-choice questions

(SMCQs), systemic true/false questions (STFQs), systemic sequencing questions (SCQs), systemic matching questions (SMQs), systemic analysis questions (SAnQs), and systemic synthesis questions (SsynQs). Tamara et al [23,24] stated that their empirical research dates since 2016 and includes one specific type of SAQs—systemic synthesis questions, SSynQs. In the very first studies, SSynQs had a constrained fill-in-the-blank format in which students were required to identify elements (*i.e.*, concepts or relationships) that were missing by filling in the empty fields in the provided diagrams. SAQs with similar structures have been applied in the study conducted by Vachliotis and colleagues [22] who have investigated whether specific forms of SAQs could be effective tools for assessing Greek high school students' meaningful understanding of organic reactions.

Tmara et al [24] highlighted that SSynQs were loaded on the "meaningful factor" within exploratory factor analysis. Also, the constrained fill-in-the-blank form of SSynQs proved to be effective as a qualitative model (*i.e.*, instructional or teaching tools) for facilitating the learning process and overcoming students learning difficulties in organic chemistry. It has been found that instruction *via* SSynQs enabled the experimental group to master educational material at a higher level when compared with the control group who received the same traditional instruction. In conclusion, the importance of this study was that the process of solving SSynQs required complex cognitive schemas developed by students.[24] In addition to this, the fill-in-the-blank form one type of higher-order thinking skill—systems thinking skills, within secondary school students. [8, 23,24].

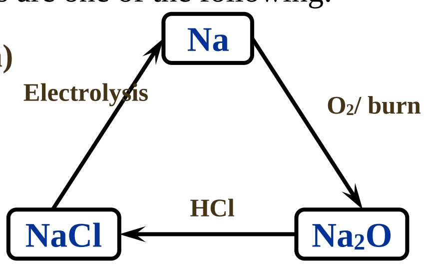
II-1-4-1: <u>Type-1: Systemic Multiple-Choice Questions (SMCQs)</u>

MCQs are the traditional choose one from a list of possible answers. However, **(SMCQs)** choose one systemic from a list of possible systemics. Each systemic represents at least three to five physical or chemical relations, between concepts, atoms, or molecules. Various examples of systemic multiple-choice questions from the fields of general, inorganic, heterocyclic, and physical chemistry are published by Fahmy & Lagowski (7, 17-20).

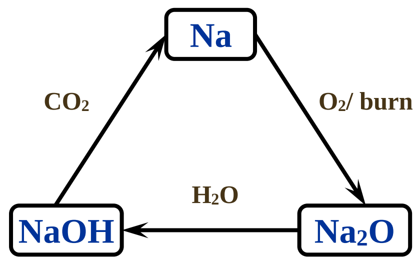
<u>Form-1: Choose from Triangular Systemics</u>:

Put (√) in front of the correct systemic diagram. Examples:

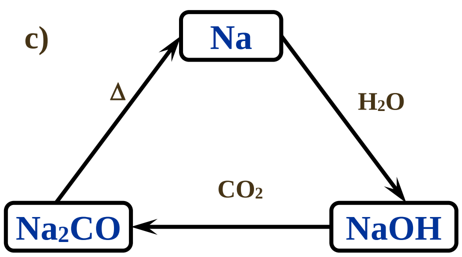
Q1. The systemic diagram represents the correct chemical relations between Sodium and its related compounds are one of the following:

a)


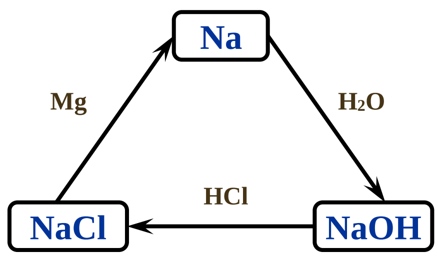
(……)

b)


(……)

c)


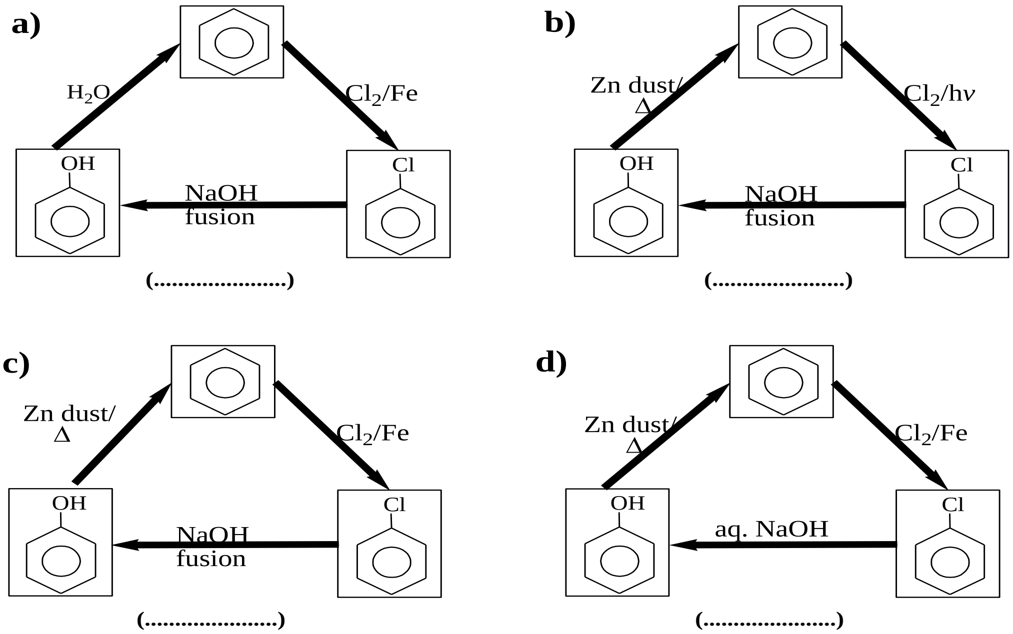
(……)

d)


(……)

- **<u>Answer: (a) √</u>**

Q2: The systemic diagram represents the correct chemical relations between benzene, chlorobenzene, and phenol is one of the following:



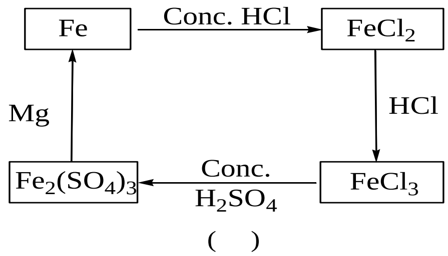
<u>Answer: (c) √</u>

<u>Form (II)</u>: <u>Choose between quadrilateral systemics:</u>

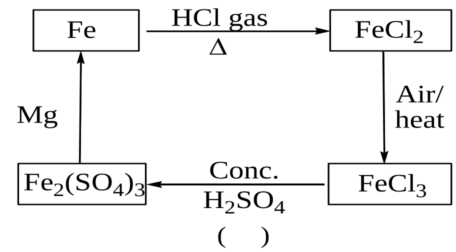
Put (√) in front of the correct systemic diagram:

Q3) The systemic diagram represents the correct chemical relations between (Fe) and its related compounds are one of the following:

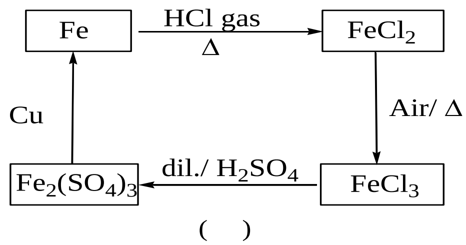
(a)



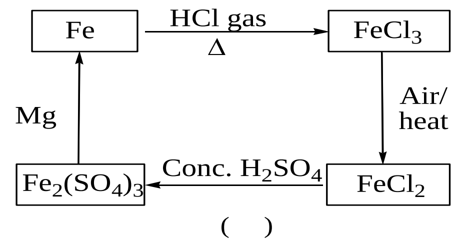
(b)



(c)



(d)

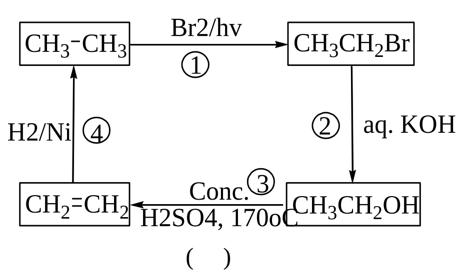


Answer: (b) √

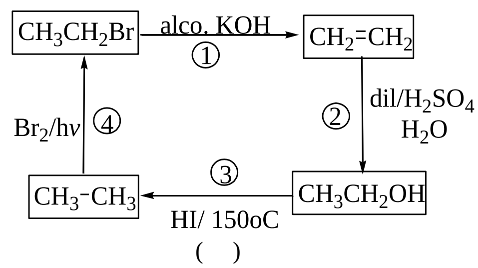
Q4: The systemic diagram represents the following reactions sequence.

[Substitution –Substitution –Elimination – Addition] is one of the following:

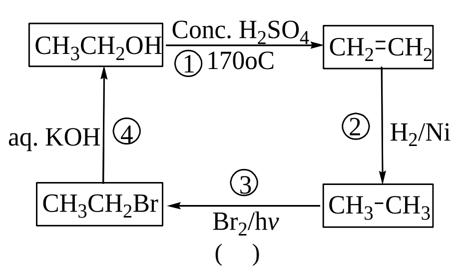
(a)



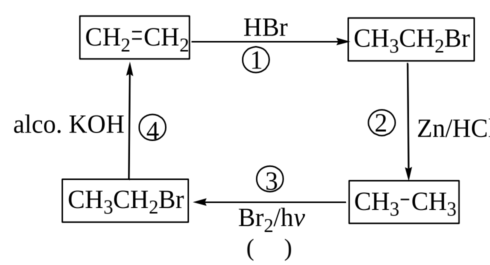
(b)



(c)



(d)



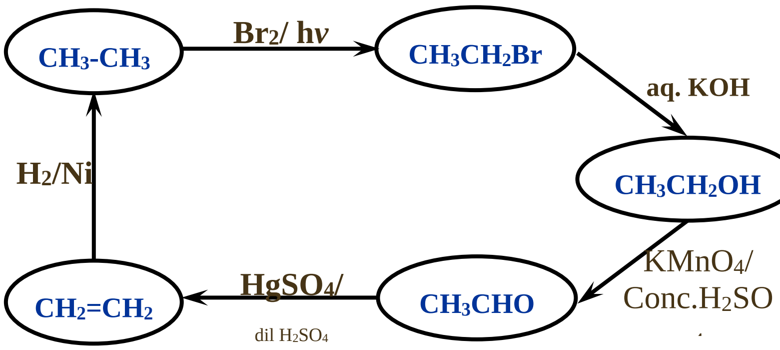
Answer: (a) √

Form (III): Choose between pentagonal systemics:

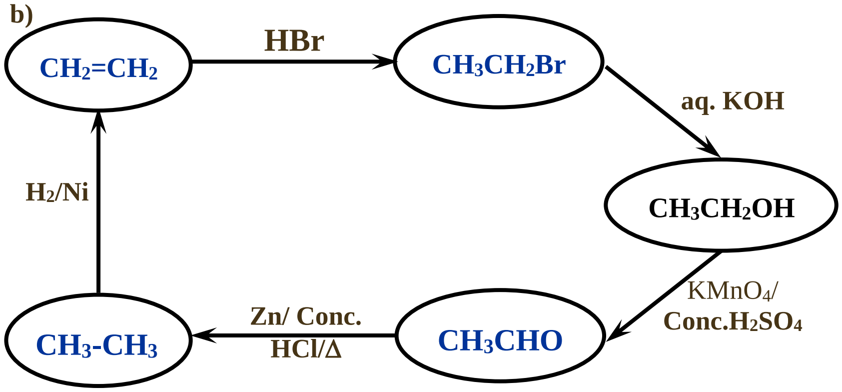
Put (√) in front of the correct systemic diagram:

Q5. The systemic diagram represents the correct chemical relations between Ethylene, Ethane, Acetaldehyde, ethyl bromide and ethanol is one of the following:

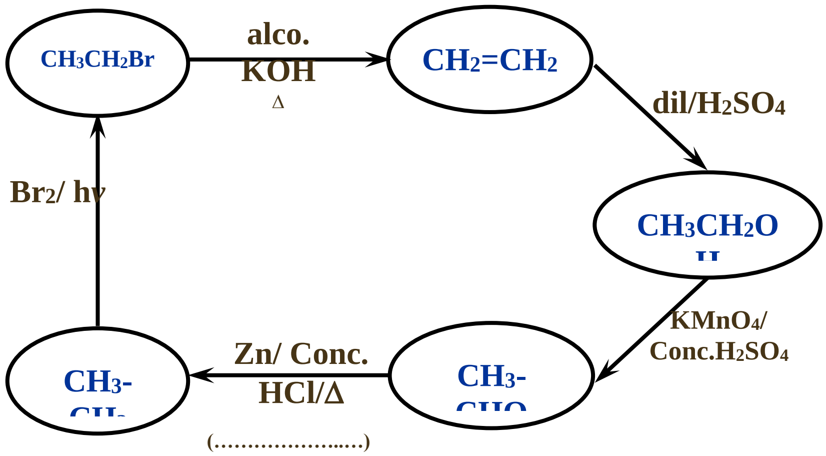
a)



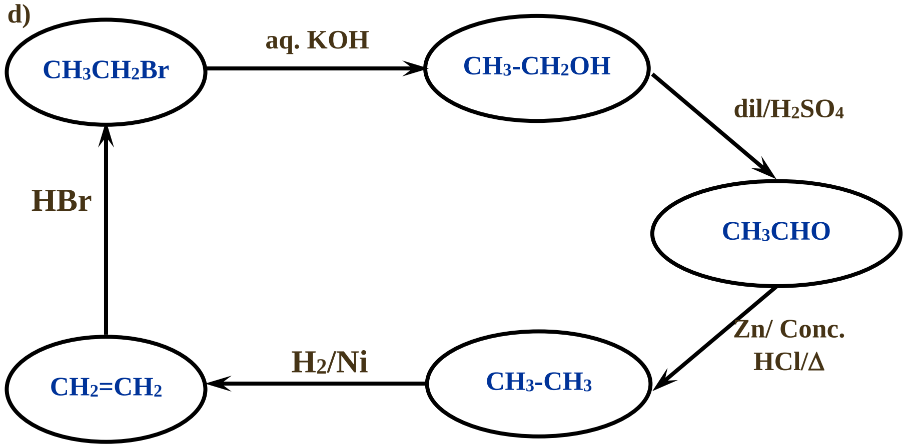
b)



c)



d)



II-4-2.: <u>TYPE-2</u>: <u>Systemic True False Questions [STFQ, s]:</u>

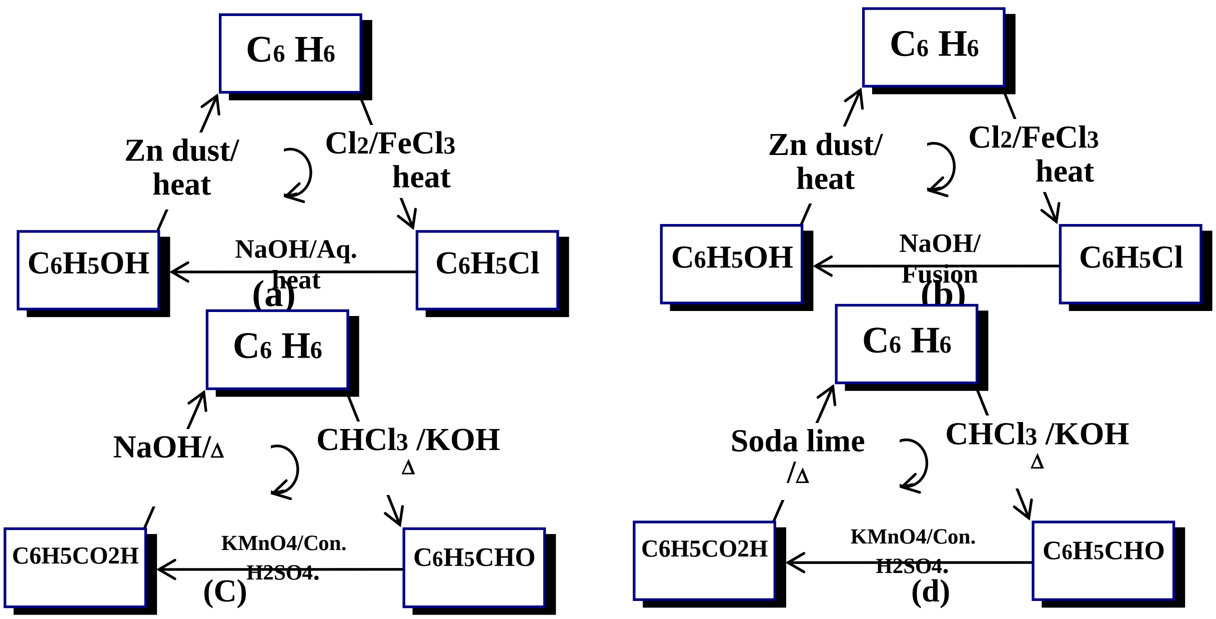
STFQs, s are well suited for testing student comprehension, synthesis and analysis, and require a student to assess whether a systemic is true or false. The advantages of [STFQ, S] are students can respond to many **STFQs,** covering a lot of concepts & facts and their relations in a short time. Student can assess higher-order thinking skills in which students can analyze, synthesize, and evaluate, and teachers can easily score **STFQs, s** [7,19].

<u>Put (√) in front of the correct systemics:</u>

Examples:

Form-1: Choose from triangular systemics:

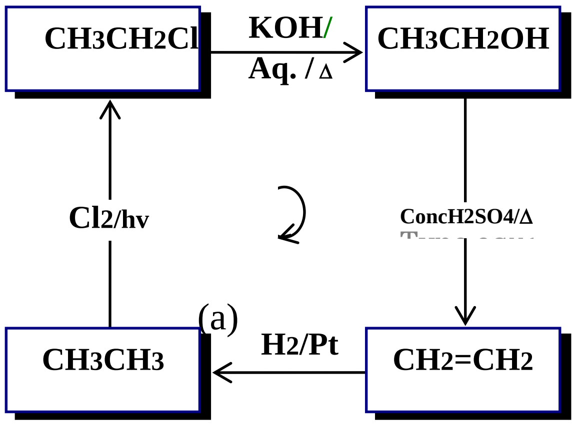
Q 1- Which of the following systemics are true and which are False:

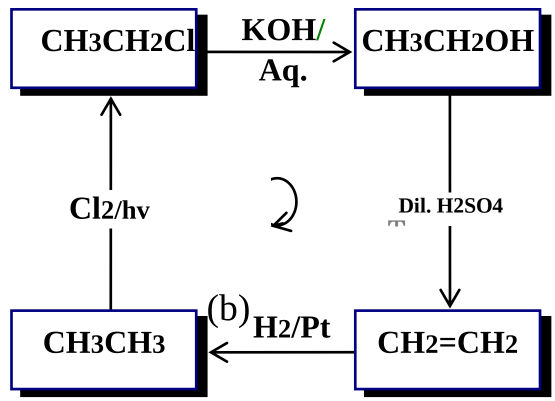


<u>Answer (1)</u> : <u>True systemics (b, d) (√); False Systemics (a, c) (X).</u>

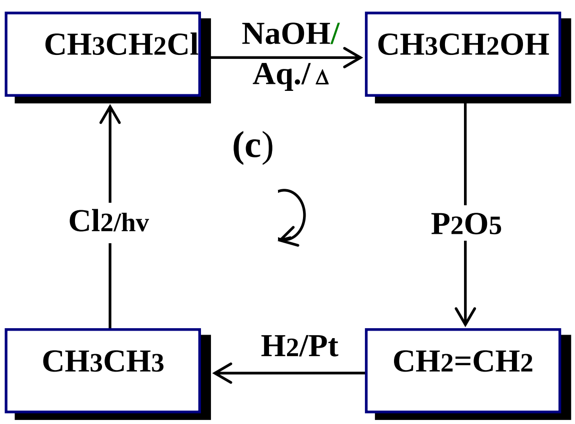
Form-2: Choose from quadrilateral systemics:

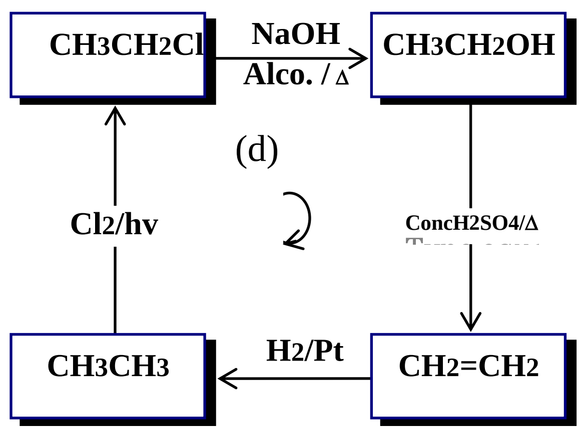
Q2: Which of the following systemics are true and which are false:





(

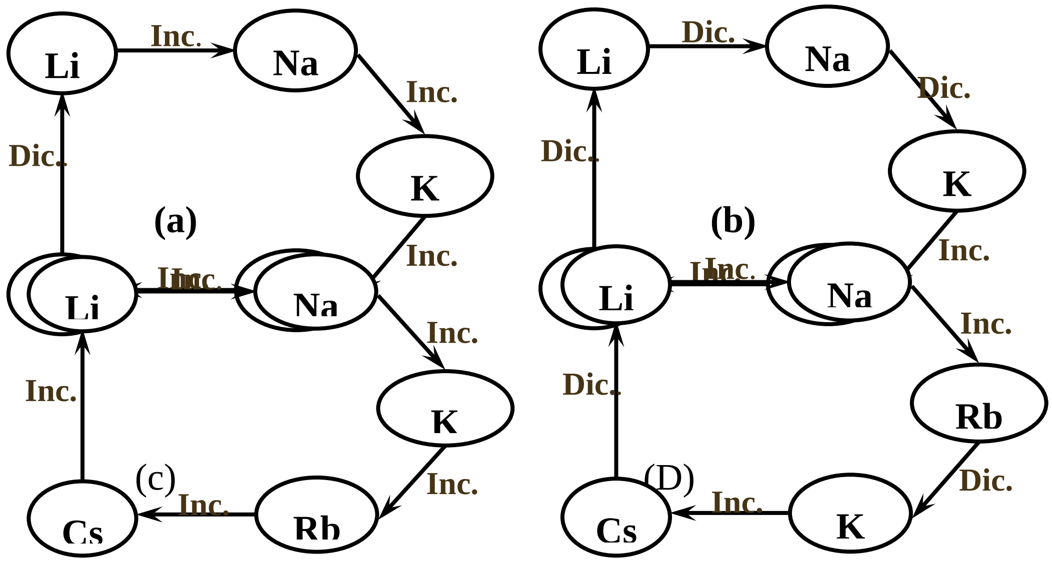




Answer (2): True systemics (a, c) (√); False Systemics (b, d) (X)

Form-3: Choose from pentagonal systemics.

Q3: Which of the following systemics are true and which are false according to the basicity:



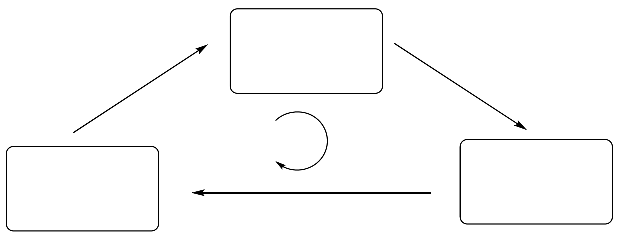
Answer (3) True systemics (a, d) (√); False Systemics (b, c) (X)

II-4-2.:TYPE3: -Systemic Matching Questions: [SMQ,s] (7,20)

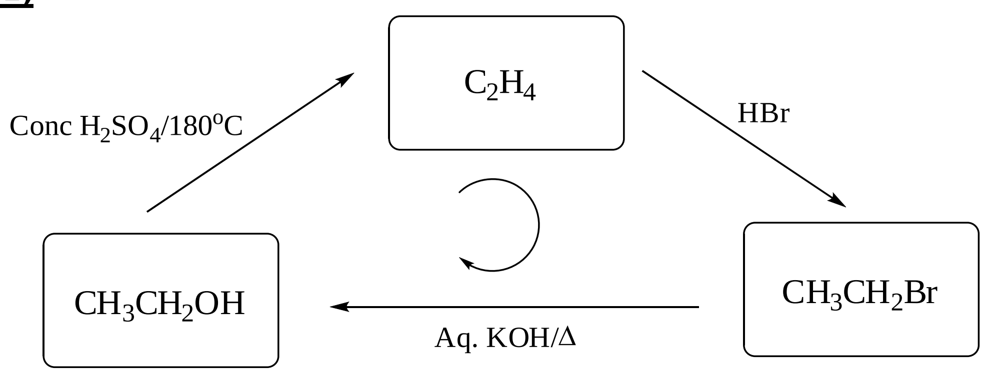
Measure the student's ability to find the relationship between a set of similar items, each of which has two components, Measure the student's ability to find the relationship between a set of similar items, each of which has two components.

<u>Form I</u>: <u>Matching on Trigonal Systemics</u>

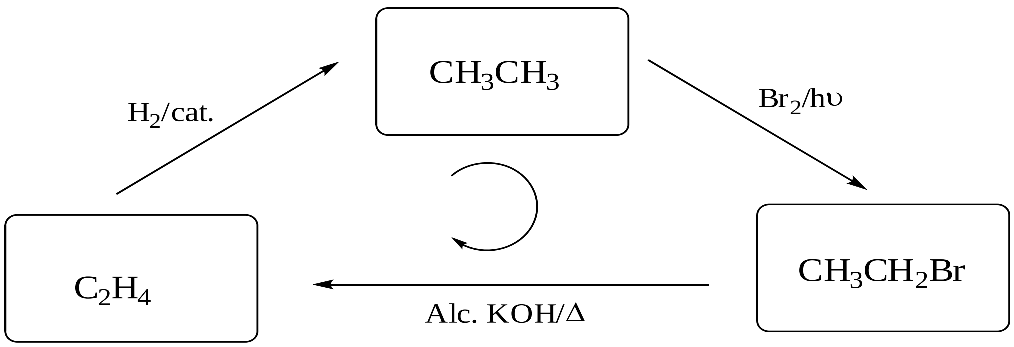
Q_1) Choose aliphatic compounds from column (A) and reaction conditions from column (B) to build the systemic diagram in column (C):

(A)	**(C)**	**(B)**
C_2H_4 CH_3CH_3 CH_3CH_2OH CH_3CH_2Br		dil. H_2SO_4 Conc $H_2SO_4/180^{O}C$ PBr_3 Alc. KOH/Δ Aq. KOH/Δ HBr H_2/cat. $Br_2/h\nu$

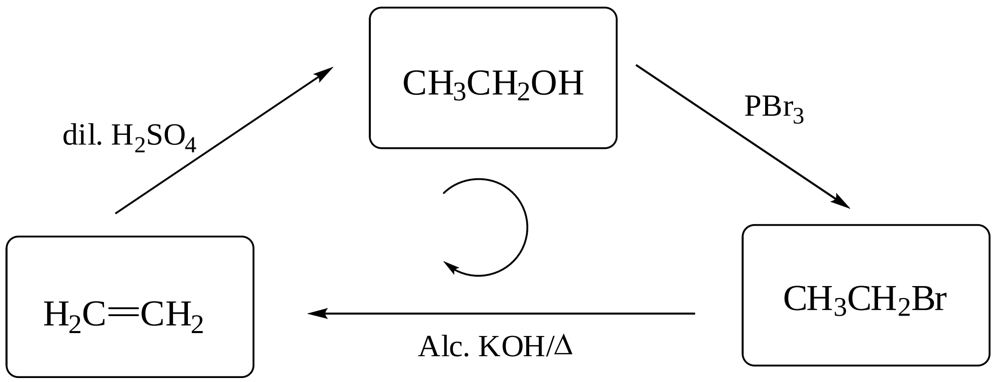
<u>Answer (1)</u>



<u>Answer (2)</u>

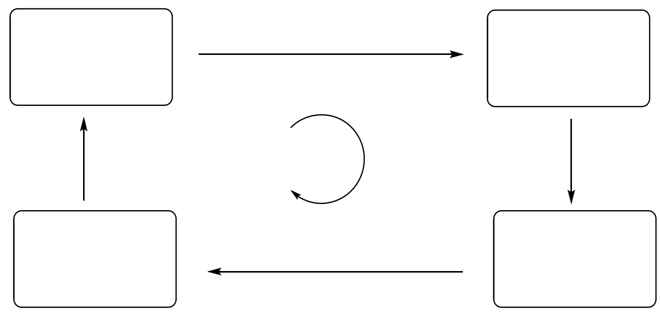


Answer (3)

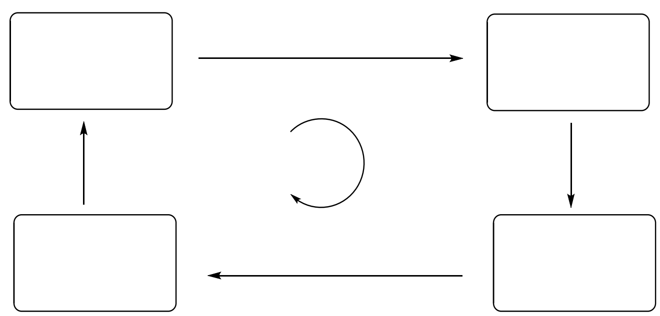


Form II: Matching on Quadrilateral Systemics

Q_2) Choose compounds from column (A) and reaction conditions from column (B) to build the systemic diagram in column (C):

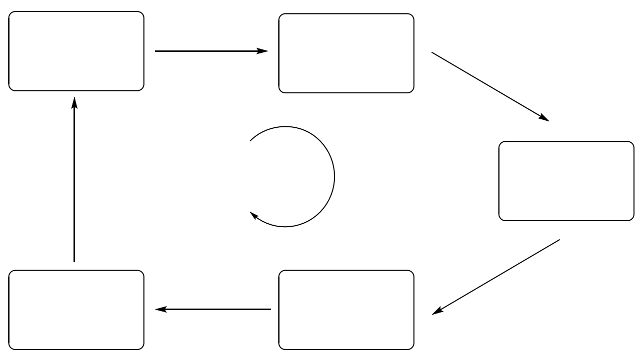
(A)	(C)	(B)
CH_4		Soda lime/heat
CH_3COOH		$KMnO_4$/ H_2SO_4
CH_3CHO		Cl_2/hν
CH_3CH_2Cl		Aq. KCN/heat
CH_3Cl		HI/P-200^oC
CH_3CH_2OH		Dil. HCl/heat
CH_3-CH_3		
CH_3CN		

Q_3) Choose compounds from column (A) and relations from column (B) to build the systemic diagram in column (C):

(A)	(C)	(B)
FCH_2COOH		**Increases**
ICH_2COOH		**Decreases**
$ClCH_2COOH$		
$BrCH_2COOH$	(according to their acidity)	

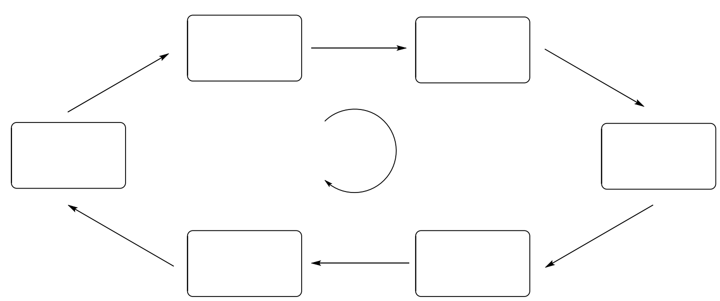
Form III: Matching on Pentagonal Systemics:

Q_4) Choose aliphatic compounds from column (A) and reaction conditions from column (B) to build the systemic diagram in column (C):

(A)	(C)	(B)
CH_3CH_2Br **CH_3CHO** **CH_3CH_2OH** **CH_3CH_3** **$CH_2{=}CH_2$** **$CH{\equiv}CH$**		**Alc. KOH** **Dil. H_2SO_4** **$KMnO_4$/conc. H_2SO_4** **Br_2/hv** **Zn/conc. HCl** **aq. KOH**

Form IV: Matching on Hexagonal Systemics

Q_5) Choose elements from column (A) and relations from column (B) to build the systemic diagram in column (C):

(A)	(C)	(B)
Sulphur **Aluminium** **Phosphorous** **Silicon** **Aluminium** **Magnesium** **Lithium** **potassium**	 **(Electronegativity)**	**Increase** **Decrease**

II-4-2.:TYPE4: -Systemic Synthesis Questions: [SSnQ,s] [7,20,22,23]

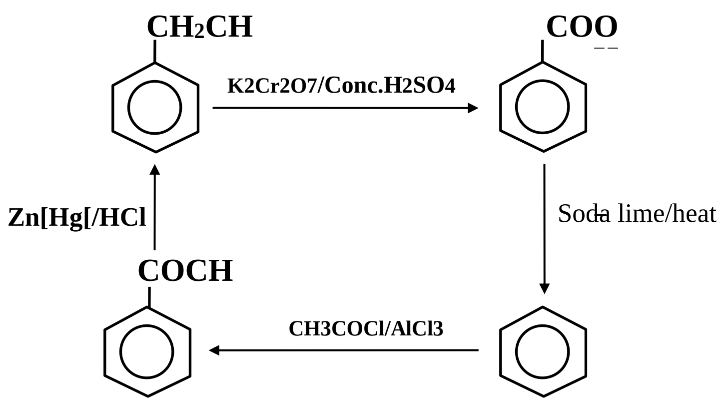
Requires student to synthesize systemic relations between concepts, facts, atoms or formulas, and their relations.

Form-1: Synthesize Quadrilateral Systemics:

Q 1: Draw systemic diagram illustrating the systemic chemical relations between the following aromatic compounds:

[Benzoic acid, Benzene, Ethylbenzene, Acetophenone]

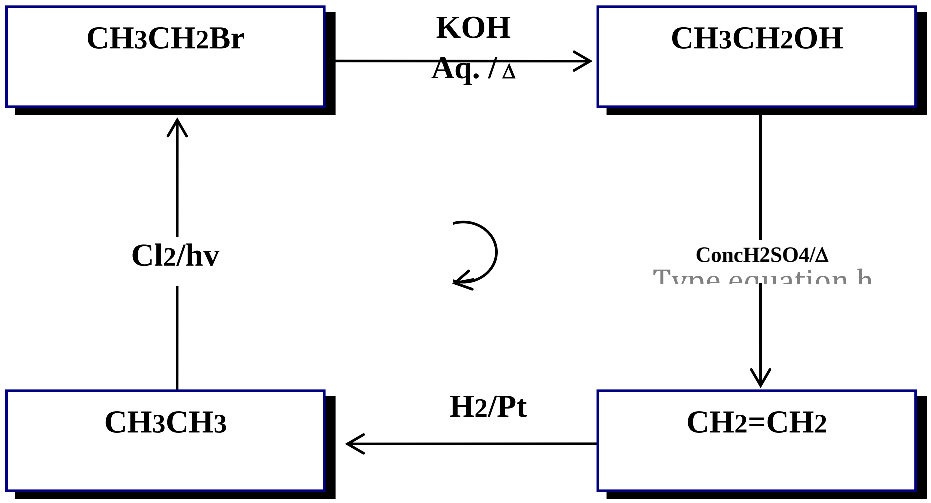
Answer (1):



Q2: Draw a systemic diagram illustrating the systemic chemical relations between the following aliphatic compounds:

[Ethanol, Ethane, Ethylene, Ethyl bromide]

Answer (2):

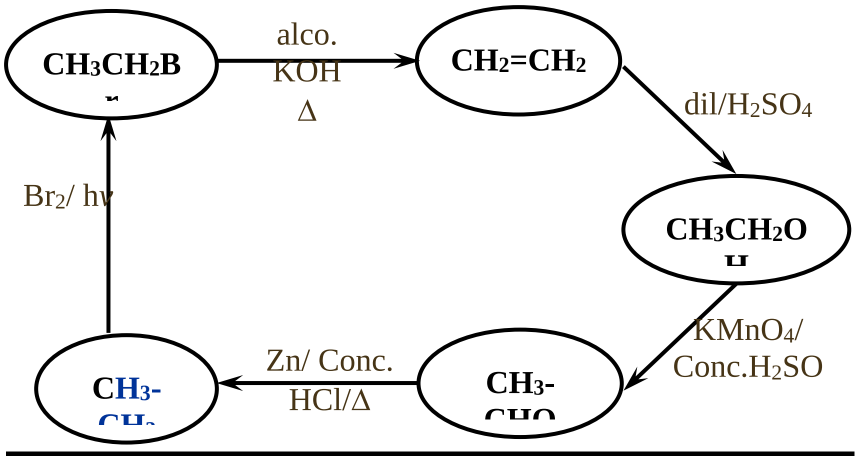


Form-2: Synthesize Pentagonal Systemics:

Q3: Draw systemic diagram illustrating the systemic relations between the following aliphatic compounds:

[C_2H_5Br, C_2H_4, C_2H_6, CH_3CHO, C_2H_5OH]

Answer (3):

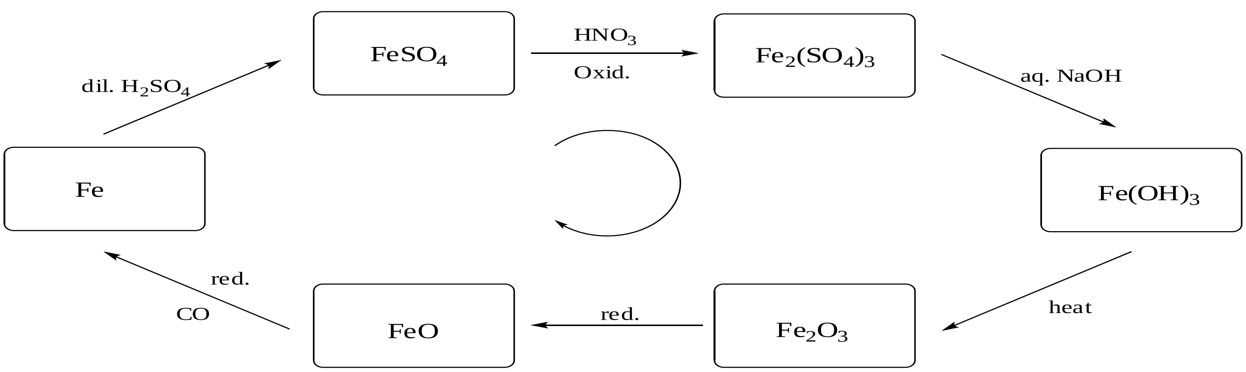


Form (3) : Synthesize Hexagonal Systemics:

Q5) Draw systemic diagram illustrating the systemic chemical relations between Iron and the following related compounds.

[$Fe_2(SO_4)_3$, $FeSO_4$, Fe, FeO, Fe_2O_3, $Fe(OH)_3$

Answer (5):



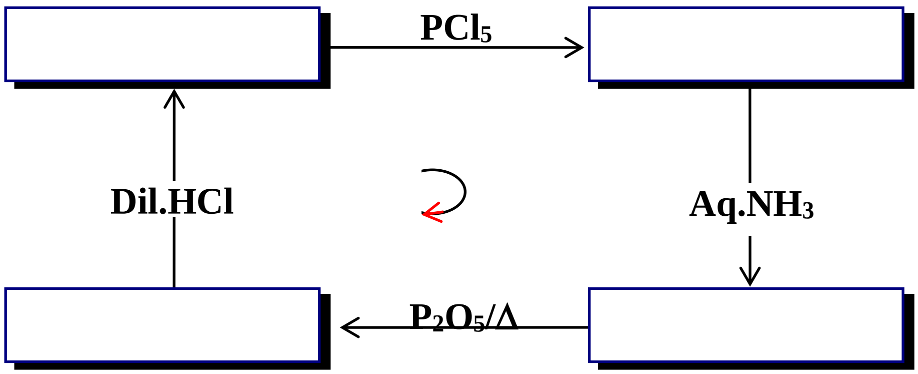
IV.2.2. Type-5: -Systemic Sequencing Questions: [SSQs](19)

SSQs require the student to position text or formula in a given Sequence in a systemic diagram and can assess higher-order thinking skills.

Examples:

Q1: Arrange the given compounds in the right places of the Systemic diagram:]

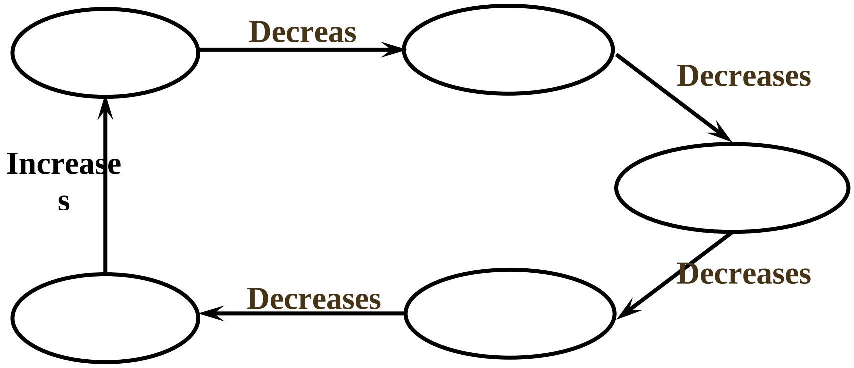
[C_6H_5COCl, C_6H_5CN, $C_6H_5CONH_2$, C_6H_5COOH]



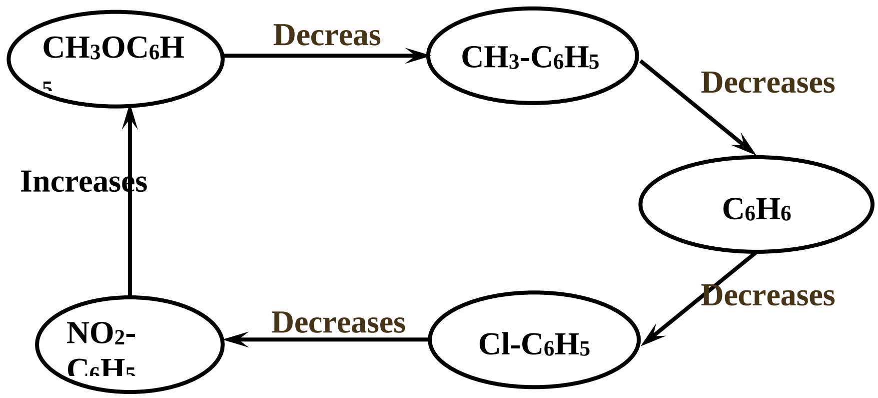
Form-2: Sequencing on Pentagonal Systemic:

Q2: Arrange the given aromatic compounds in the right places of the following systemic diagram according to the ease of Nitration.

[$CH_3C_6H_5$, Cl-C_6H_5, CH_3O-C_6H_5, NO_2-C_6H_5, C_6H_6]



Answer (2):



III-SYSTEMIC THINKING [ST]

Systemic thinking is a simple technique for gaining systemic insights into complex problems. Conventional [Linear] thinking techniques are fundamentally analytic. Systemic thinking is a combination of analytic thinking with synthetic thinking. It is based on the fact that everything is Systemic & interacts with everything around it (Fahmy, 7). Systemic thinking is a powerful problem-solving approach that includes a variety of tools and methods. Generally used as a way to diagnose complex and cross-functional issues in business operations and technical workflows, systemic thinking focuses on the 'system' as a whole (*UK Indeed Team Dec.2022*) (25).

III-1: What is The Systemic Thinking ?(25)

-Systemic thinking, or systems thinking, is a comprehensive analytical approach to understanding how different elements interact within a system or structure. Commonly used for research and development purposes in scientific, human resources, medical, economic and environmental studies. Systemic thinking is a holistic approach that helps contextualize information. Systemic thinking includes studying all components and their influence on each other. Systemic thinking combines analytical thinking with synthetical thinking to find a system-wide focus to gain systemic deep insights into complex situations and problems.

III-2: Advantages of Systemic Thinking:(25)

- It offers the potential to find systemic focus in any situation.
- Helps identify interconnectedness rather than exclusively studying the elements individually and how these elements interact with one another &what is the result.

- Improves the entire system instead of improving the performance or efficiency of one part of the system and leaving the rest of the structures**.**
- Enables us to deal with the elements of any situation in harmony rather than in isolation.
- Enables anyone can use it to gain deeper insight about anything**.**
- Takes feedback into account by incorporating feedback at each stage. This leads to limiting the Margin of Error and improves efficiency.

III-3: How do we enhance systemic thinking?

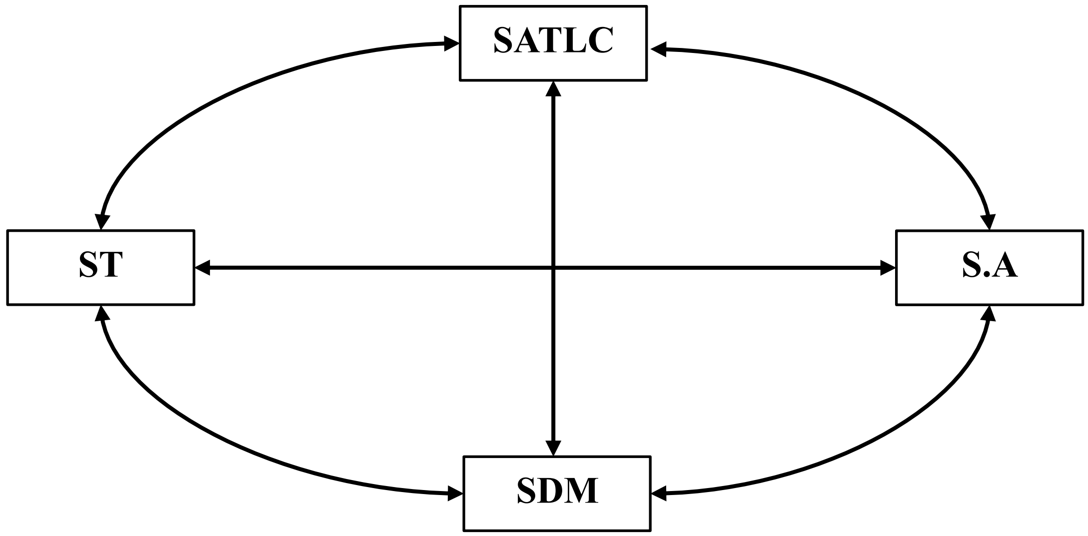
Vachliotis et.al [9,22] stated that systemic assessment questions [SAQs] were designed to be used effectively to assess meaningful understanding and systems thinking after students become familiar with a particular teaching theme. They examined secondary school students' systems thinking skills in an organic chemistry domain. For this purpose, they constructed and evaluated fill-in-the-blank systemic assessment questions [SAQs]. Herin et al (8.23,24) explained the fact that instruction via [SSynQs] brought students to a level in which they could not only identify the initial concepts (organic compounds) and simple relations but also effectively "transform" such concepts within the selected system. These findings could be considered valuable for future research, in which other types of [SAQs] (Fahmy [7,18-21] should be constructed and examined as tools for assessing different aspects of systems thinking construct.

SUMMARY

We can summarize the above-mentioned systemic activities [Systemic approach to teaching and learning chemistry (SATLC), Systemic assessment (SA) and Systemic thinking (ST)], in the following systemic diagram under the title of systemic education reform [SER]. Systemic diagram illustrating the Systemic Education Reform. (7)

Systemic diagram illustrating the Systemic Education Reform.

Each systemic component interacts with the other components systemically.SA was used to assess students' achievements after being exposed to SATLC. However, SA is used to enhance ST. Also, ST is one of the important learning outcomes of SATLC & very important in the preparation of systemic creative thinkers which is one of the important demands for Systemic Decision-Making [SDM].



ACKNOWLEDGEMENT

I would like to acknowledge the late Prof. Joe Lagowski [University of Texas at Austin, USA]. He passed away on 29 April 2014. He is the co-founder of SATLC & SAQ with me. We have jointly developed this approach internationally since the year 1998.

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SYSTEMIC APPROACH FOR TEACHING AND LEARNING GREEN CHEMISTRY (SATLGC)

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ABSTRACT

Green chemistry courses have been recently described in the chemistry education curriculum. Its teaching and learning strategy include course content, student assessments, and pedagogical style. Current trends in education research and practice have established the importance of the intended learning outcomes and the effectiveness of high-impact practices, active learning, and inclusive teaching. In this article we designed the pedagogy for teaching and learning green chemistry through the systemic approach (SATLC). *[African Journal of Chemical Education—AJCE 13(4), December 2023]*

INTRODUCTION

Systemic Approach in Teaching and Learning Chemistry (SATLC) **[1- 9]** which. means study of chemistry concepts through interacted systems in which all relationships between concepts are clear. Chemistry is the core of all other science subjects due its special concepts and importance. But many are considered chemistry as a very complicated discipline of science, starting from atomic structure, reaction kinetics, energetics of bond breaking and formation, micro-molecules, to macromolecular compounds. All of chemical processes require deep understanding of the chemical concepts and basics, training on scientific thinking and inquiry and also, problem-solving skills. However, there are some challenges facing chemistry, such as the word "chemicals" which has become linked with environmental pollution, unsustainable growth and unhealthy toxins. meanwhile there is the word green chemistry, which is *the design of chemical products and processes that reduce or eliminate the use or generation of* hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal.

Although there are tremendous developments in science as genera and in chemistry as particular, many students prefer studying other disciplines than chemistry, even if they have interest in science due to its difficulty in understanding. Moreover, many teachers are not up to the job of inspiring and not enthusing to their students, due to their traditional lecturing style as it allowed for maximum content coverage, and it was the mode with which they were most familiar.

Enthusiasm is crucially needed in teaching and learning of chemistry at educational and should be addressed on top priority. In this scenario the role of the instructor is of vital significance. A teacher can minimize the difficulties in concept building by providing better perspective related to the basics of the subject. This can be accomplished through novel efforts involving personal input. The recently emerged concept-based teaching methodology, systemic approach to teaching and learning chemistry (SATLC), is a fascinating route to meet this noble endeavor. This new teaching method has been discovered to play a pivotal role, towards the efforts for promoting better understanding of chemical concepts. In addition to that, the results reported from the evaluation of SATL technique have been very promising as far as the improvements in students' academic achievements are concerned **[1-9]**.

However, to make chemistry easy, funny to learn, important and applicable, we always need to find strategies that make the above parameters are well addressed. Among the mechanisms method of teaching and using appropriate instructional materials are the important strategies used to make chemistry attractive and effective. This is a common concern, though it is our impression that many faculties involved in curriculum reform feel that the benefits provided by alternative instruction. This article will focus on systemic approach for teaching and learning green chemistry (SATLGC).

Differences between Systematic and Systemic Approach

At the beginning we should differentiate between systematic and systemic approach. Systematic, means something is well organized and arranged according to a set of plan or is grouped into systems. Whereas systemic means that something has or can affect the entire system. Systemic approach describes something that belongs to, work together with, or can affect the entire body or system as a whole [10]. We represent Figs. 1 and 2 to simplify the difference between systemic and systematic approach in a system consisted of items A, B, C, and D. In the systemic approach (Fig. 1) the items (A-D) are well arranged in an organized order so that you cannot see A through D, whereas in the systemic approach (Fig. 2), all the items (A-D), are affecting each other and seen synchronously.

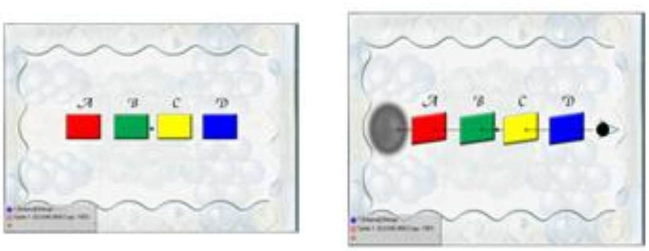

Fig.1 (Systematic Approach)

Fig.2 (Systemic Approach)

Systemic Approach for Teaching and Learning Green Chemistry

What is the Green Chemistry?

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal.

Impact of Green Chemistry on Societies Sustainability:

- Prevents pollution at the molecular level.
- Is a philosophy that applies to all areas of chemistry, not a single discipline of chemistry.
- Applies innovative scientific solutions to real-world environmental problems.
- Results in source reduction because it prevents the generation of pollution.
- Reduces the negative impacts of chemical products and processes on human health and the environment.
- Lessens and sometimes eliminates hazards from existing products and processes.
- Designs chemical products and processes to reduce their intrinsic hazards.

Differentiation between Green Chemistry and Cleaning up Pollution

Green chemistry reduces pollution at its source by minimizing or eliminating the hazards of chemical feedstock, reagents, solvents, and products.

This is unlike cleaning up pollution (also called remediation), which involves treating waste streams (end-of-the-pipe treatment) or cleanup of environmental spills and other releases. Remediation may include separating hazardous chemicals from other materials, then treating them so they are no longer hazardous or concentrating them for safe disposal. Most remediation activities do not involve green chemistry. Remediation removes hazardous materials from the environment; on the other hand, green chemistry keeps the hazardous materials from being generated in the first place.

If a technology reduces or eliminates the hazardous chemicals used to clean up environmental contaminants, this technology would also qualify as a green chemistry technology. One example is replacing a hazardous sorbent [chemical] used to capture mercury from the air for safe disposal with an effective, but nonhazardous sorbent. Using the nonhazardous sorbent means that the hazardous sorbent is never manufactured and so the remediation technology meets the definition of green chemistry.

Principles of Green Chemistry

1.Prevention of Waste

It is better to prevent waste than to treat or clean up waste after it has been created.

2.**Maximize Atom Economy**

Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3.**Design Less Hazardous Chemical Syntheses**

Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4.**Designing Safer Chemicals and Products**

Chemical products should be designed to affect their desired function while minimizing their toxicity.

5.**Use Safer Solvents and Auxiliaries/Reaction Conditions**

The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

6.**Design for Energy Efficiency**

Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

7.**Use of Renewable Feedstocks**

A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8.**Reduce Derivatives**

Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9.**Use Catalysts, Not Stoichiometric Reagents**

Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. **Design Chemicals and Products that Degrade After Use (for Degradation)**

Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. **Real-time Analysis for Pollution Prevention**

Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. **Inherently Safer Chemistry for Accident Prevention (Minimize the Potential for Accidents)**

Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Impact of Green Chemistry on Society

Green chemicals either degrade to innocuous products or are recovered for further use. Through green chemistry, plants and animals suffer less harm from toxic chemicals in the environment, lower potential for global warming, ozone depletion and smog formation, and less chemical disruption of ecosystems take place. Therefore, it is very important to integrate green chemistry in the chemistry curriculum using the most attractive methodology of teaching and learning chemistry such as the systemic approach (SATLC), in addition to the other appropriate interactive attractive educational strategies in teaching and learning chemistry such as systemic approach (SATLC), E-learning, M-learning, and any other tools in which modern technologies are integrated (Fig. 3). **[10]**

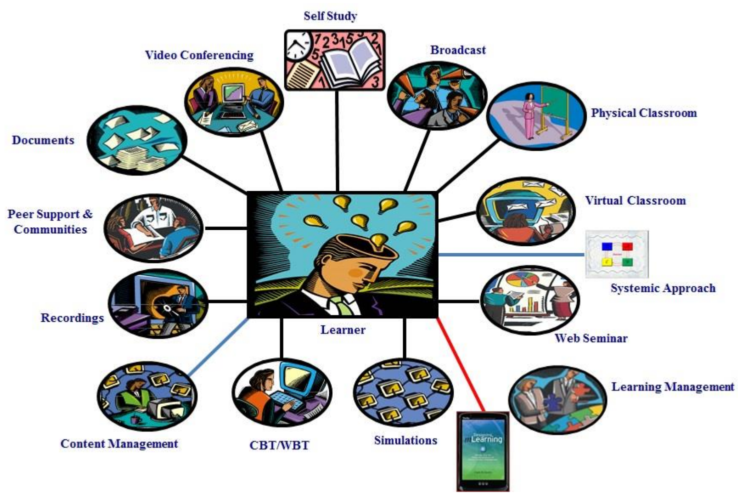

Fig. 3; Different Strategies and Methodologies in Teaching and Learning Green **Chemistry**

The goals of the green chemistry branch is to develop chemical products and processes that are less harmful for the environment and safer for workers. This article highlights some of the many ways green chemistry can be used in the daily life in consumer products, transportation, agriculture and food production, construction and packaging, pharmaceuticals, among other industries. **[12]**

Some Uses of Green Chemistry in the Daily Life (Green Society)

Uses of green chemistry in daily life are numerous, including the use of green transportation. ingredients in the food industry, new materials for construction and packaging, safer use of chemicals in agriculture and pharmaceuticals. Green chemistry is still developing but will play an increasingly important role in ensuring our wellbeing in the future Fig. 4).

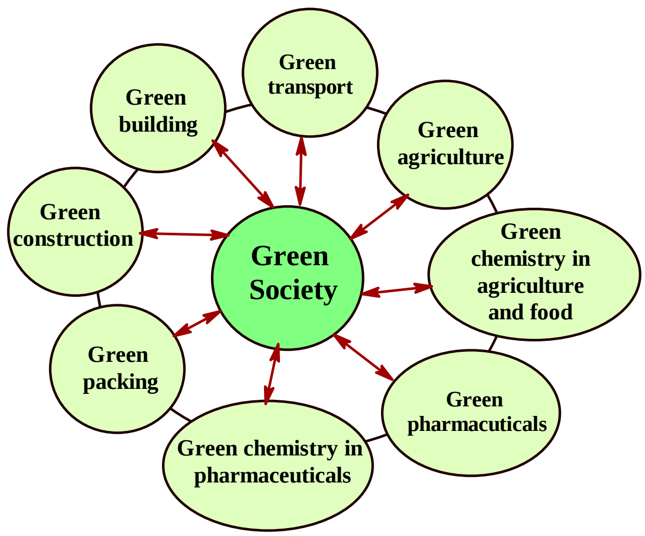

Figure 4

Challenges and Impact OF Green Chemistry Concepts on Sustainable Environmental and Social Development

Green chemistry is a cutting-edge method of creating chemical goods and processes that reduce the usage and production of harmful compounds. Utilizing renewable resources, increasing energy efficiency, and lowering waste are some of its key objectives to avoid pollution at its source and promote sustainability. With environmental issues including climate change, resource depletion, and hazardous pollution, green chemistry concepts are becoming more and more crucial **[13]**. The 12 Principles of green chemistry are becoming understood as crucial for the chemical industry's growth and hence societies sustainability. However, implementing green chemistry is challenging due to several factors, such as lack of knowledge, expense, technical problems, regulatory barriers, and a lack of government backing. To encourage the use of green chemistry concepts in business it should be publicized through the governments, industries community, society and it should be integrated in the academia, i.e., chemistry curriculum at all levels starting from schools (K-12) to higher education.

This article recommends integrating the green chemistry in the curricula of chemistry at all levels due to its important impact on the societies sustainability and improvements, with the concentration on the interrelationships between its principles, using attractive and interactive teaching and learning methodologies such as (SATLGC) to encourage its practice that leading to benefit the environment and the economy.

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A SOLUTION TO DECIPHER SATL APPROACH FOR TEACHING "SOLUTIONS" IN CHEMISTRY

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ABSTRACT

Solutions are a fundamental unit to be discussed in chemistry. The measurable changes in terms of chemical and physical properties of solutions occur when different interlinking parameters that affect the properties of solutions are altered. It is important to understand this interactive behavior in order to comprehend this basic concept and to develop new applications. Nothing has yet been documented to explain the concept in SATL learning approach. Hence, an easy systemic approach to learn this vital component of chemistry has been devised here. *[African Journal of Chemical Education—AJCE 13(4), December 2023]*

INTRODUCTION

Several strategies are available for enhancing the teaching and learning of scientific subjects in general, and chemistry in particular. These are systemic approaches that make understanding of concept much easier than the traditional system of teaching. There have been many teaching options continued to be reported in literature that points up the chemistry basics to facilitate and enhance its effectiveness in teaching and learning. In the past decade, creative and visionary way of teaching and learning through systemic approach (SATL) has been introduced (1-4) for this end. The basic promising goal of this approach is to make the subject more accessible by providing them the opportunities to explore the concepts, hence change the rote learning path to constructive learning. Amusable defines the meaningful (deep) learning (5) as the formulation of non- arbitrary relationships between thoughts in the learners' mind. Gilbert and Justi states that a**uthentic chemistry education, which mirrors the actual practice of science, is achieved through a meaningful learning approach** (6).

According to Novack (7) meaningful learning means that learners deal with a learning task by attempting to form relationships between newly and previously learned concepts. Michael (8) stated that meaningful learning occurs when the learner interprets, relates, and incorporates new information with existing knowledge and applies the new information to solve novel problems.

In Systemic Approach in Teaching and Learning Chemistry (SATLC) the concepts are positioned in such a way that the relations between a series of ideas and issues are made logical. SATLC emphasizes the interlinking of the various concepts of chemistry and a **number of chemistry-related issues have already been addressed by implementing SATL approach. (9-13).**

It is known for SATL (Systemic Approach in Teaching and Learning) that systemic diagram (SD0) is the initial for pointing out and discussing any issue and is based primarily on the previous knowledge of students. After inclusion of similar systemics with known and unknown relationships (SD1, SD2 and so on) the unit ends at final systemic diagram (SDf) as in Figure 1). In (SDf) students can understand the connectivity of different concepts that how are these related to each other (14-15).

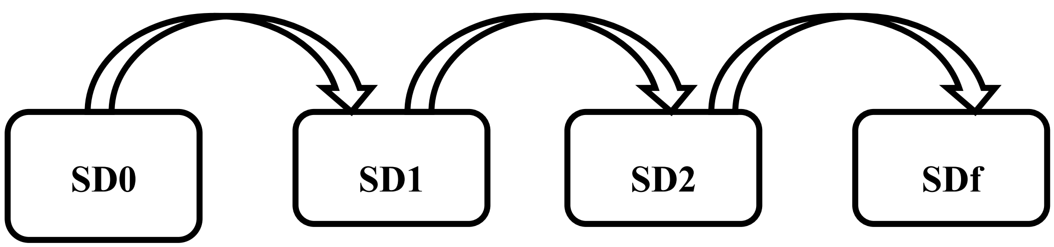

Figure 1: Systemic approach stratagem

Several systemic diagrams on a variety of topics can be developed and finally all of these may be assembled together (Figure 2) (16).

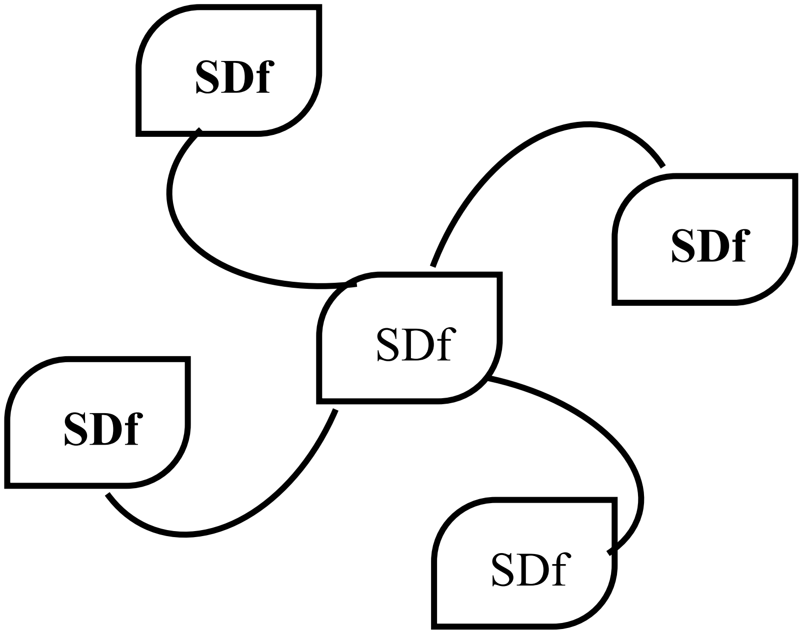

Figure-2: Association of final systemic diagrams (SDf) on various topics.

METHODOLOGY

General chemistry is one of the important branches of Chemistry. It deals with various fundamental concepts to monitor the chemical reaction. This topic has been chosen to enlighten the effectiveness of systemic approach to teaching and learning (SATL) methodology in general chemistry. Generally linear approach has been adopted to convey this subject matter. Figure 3 is based on the linear relationships among various concepts of chemistry. The relationships (1-6) are sequences of linear associations. Figure 3 can be transformed into systemic diagram SD0 as represented in Figure 4.

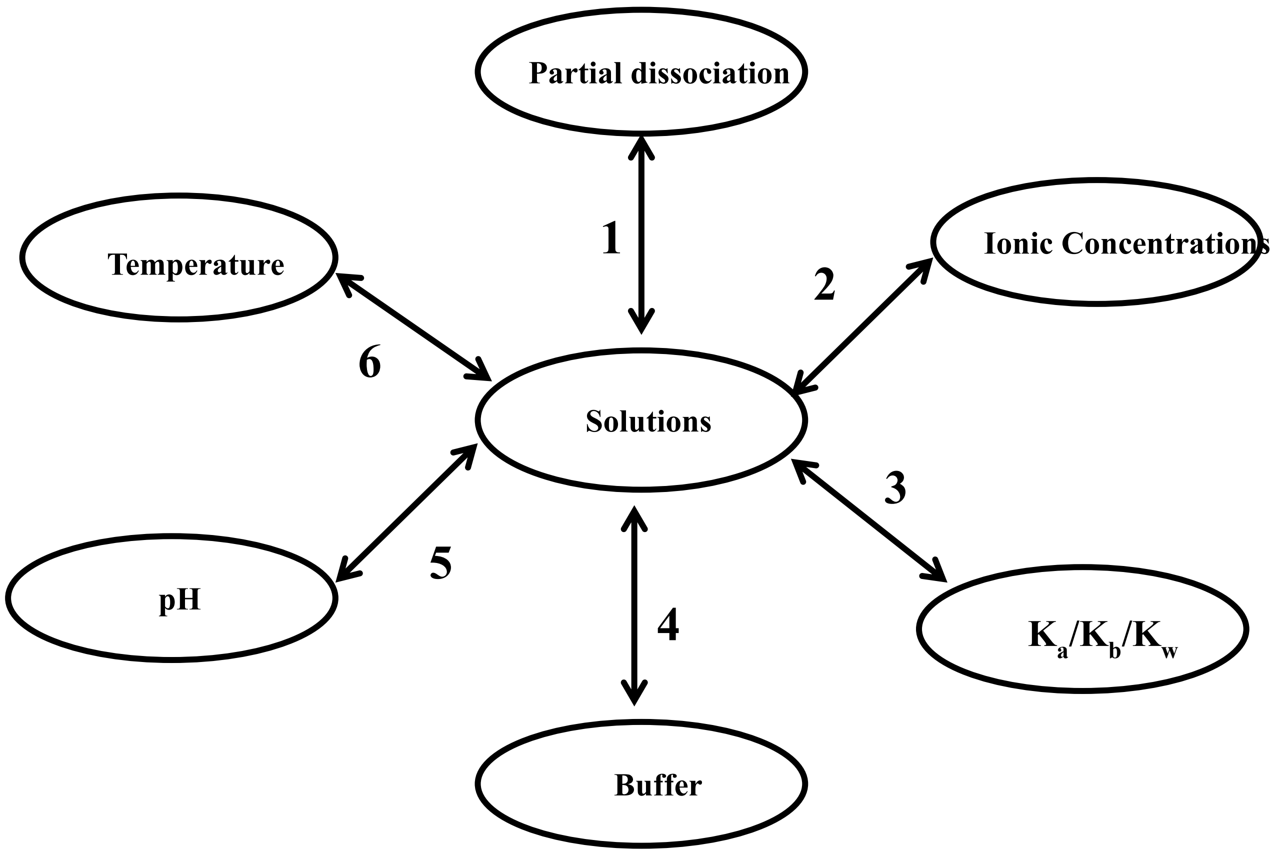

Figure 3: Linear relationships among different concept of chemistry required to study the concept of solution

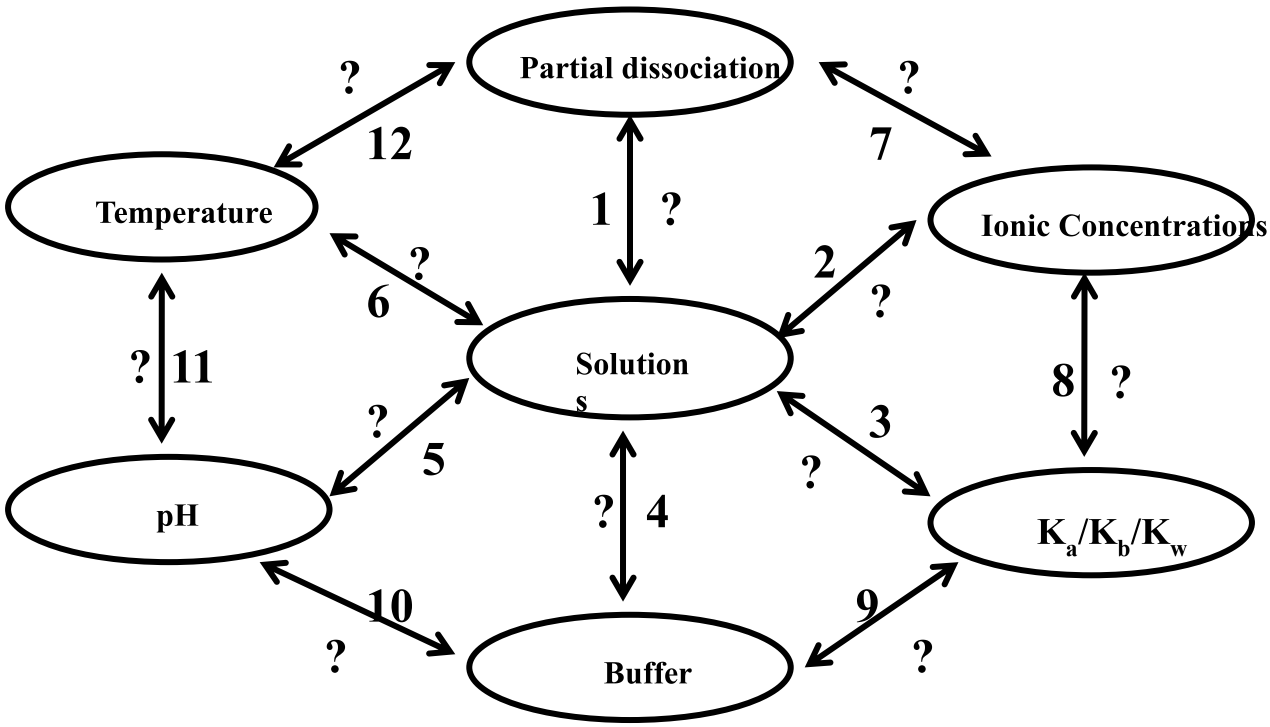

Figure 4: SD0

Systemic diagram (SD0) (Figure 4) sketches that all the relationships are unfamiliar. The interpretation of these relationships can be acquired by applying Systemic approach. Following the clarification of role of partial dissociation of the chemical species in a solution (1) and its connection with ionic concentration (7), which may also affect the various properties of solution (2), SD0 can be renewed into another systemic diagram i.e., SD1(Figure 5).

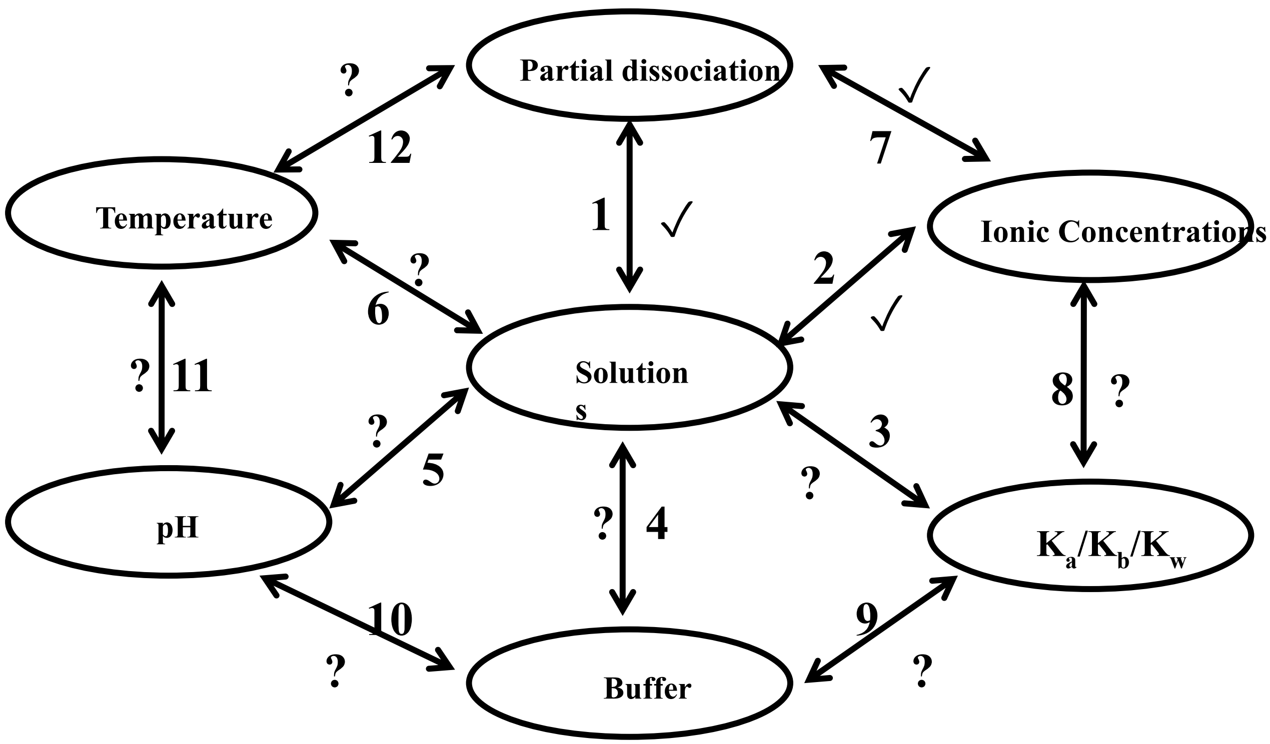

Figure 5: SD1

Figure 5 is not yet fully deciphered and still there are the links need to be figured out. Once decoded, these links will reveal Figure 5 to Figure 6 (SD2)**.**

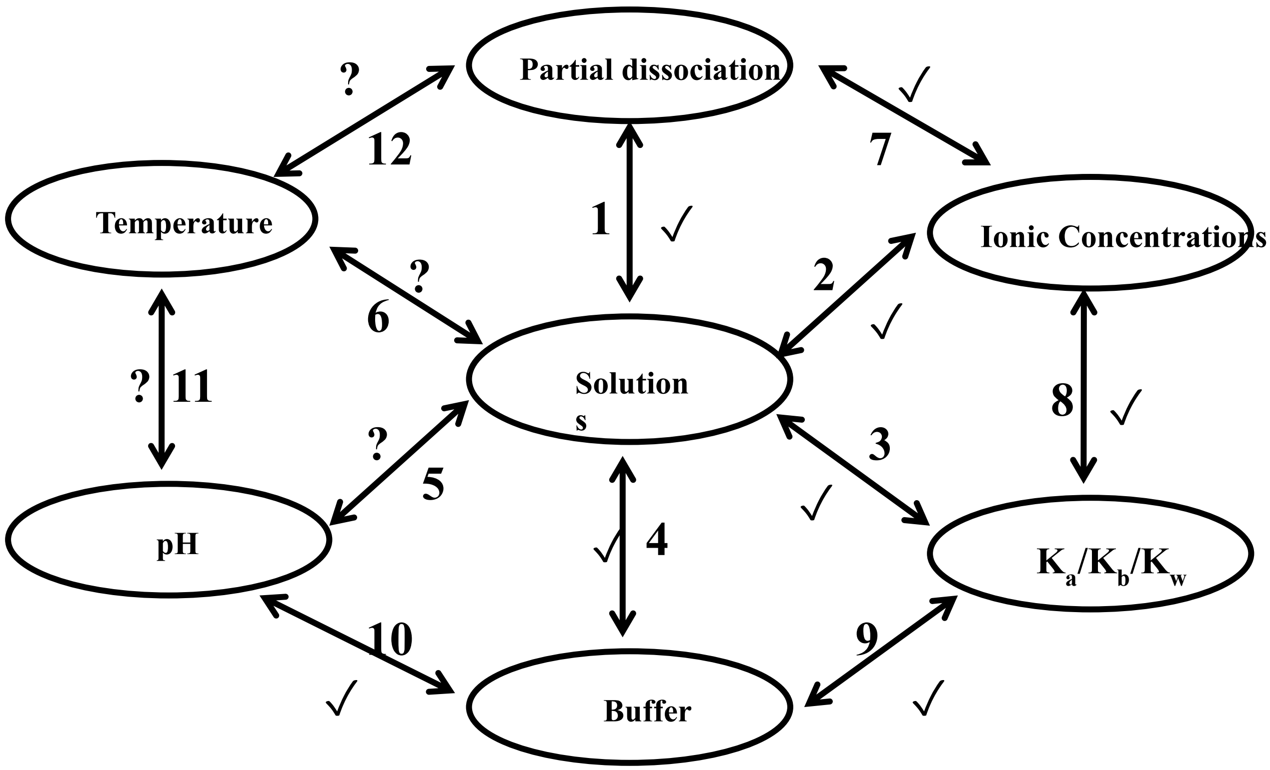

Figure 6: SD2

The remaining connectivity of systemic diagram (SD2) for example: relevance of the pH (5) and the nature of buffer (4), their association with each other such as temperature (11) and with the partial dissociation (12) can be determined to obtain final systemic diagram (SDf), Figure 7.

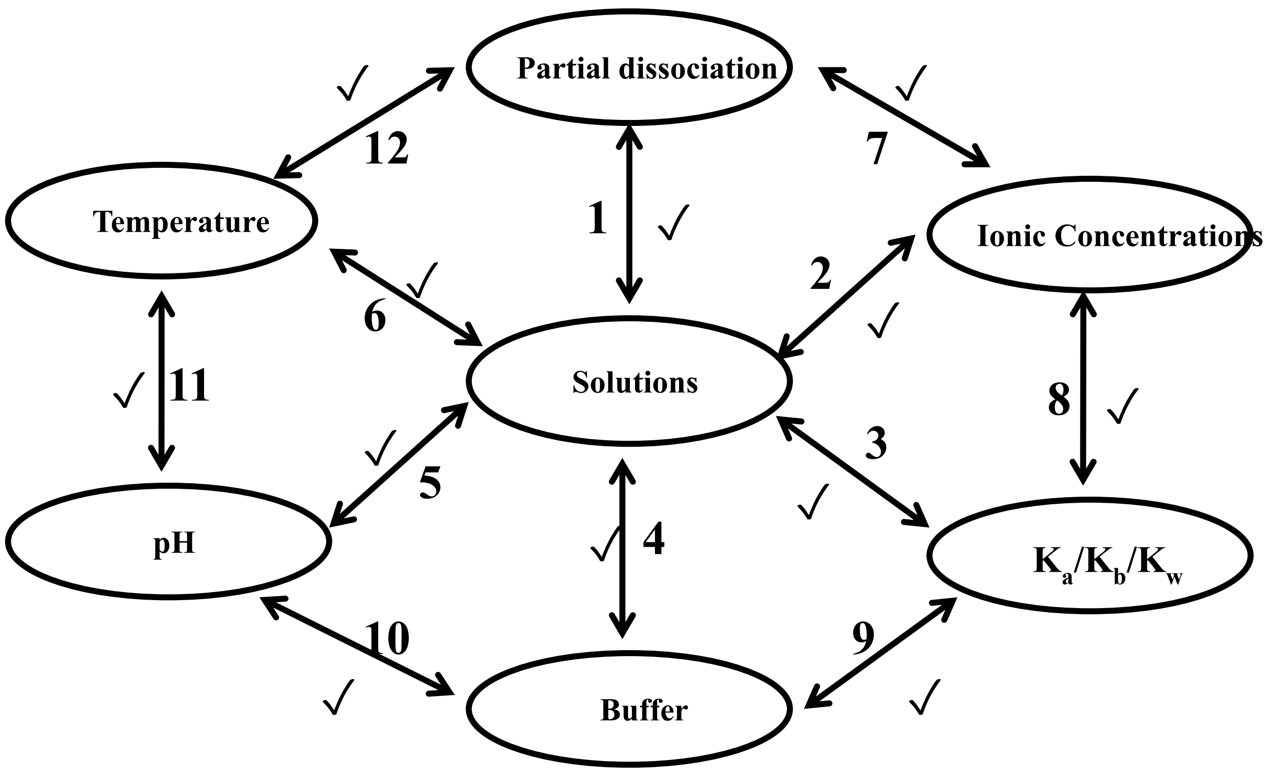

Figure 7: Final Systemic Diagram (SDf)

Similarly, several other systemic diagrams can be developed (Figures 8-13) relating solution relation to the parameters involved in the chemical kinetics. Finally, all these systemic diagrams can be linked to Figure 7 to provide a wide perceptive of this important field of chemistry.

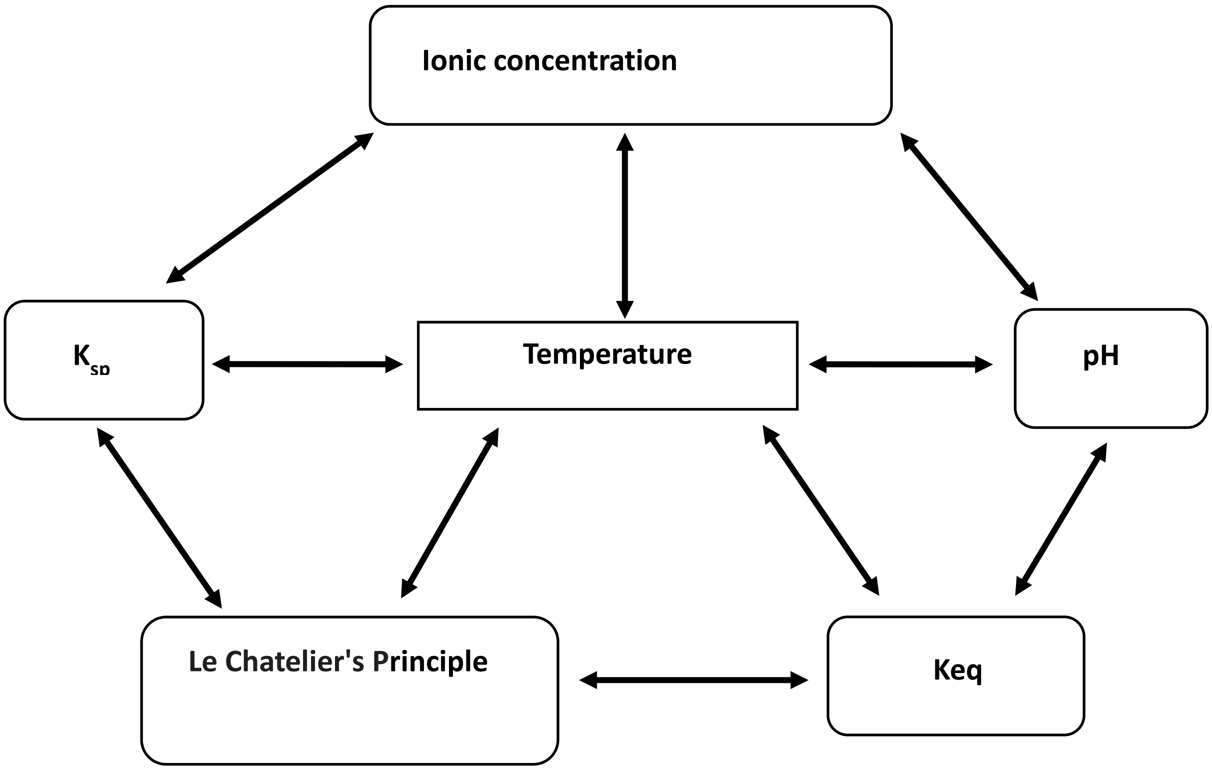

Figure 8: Systemic diagram to explain the temperature

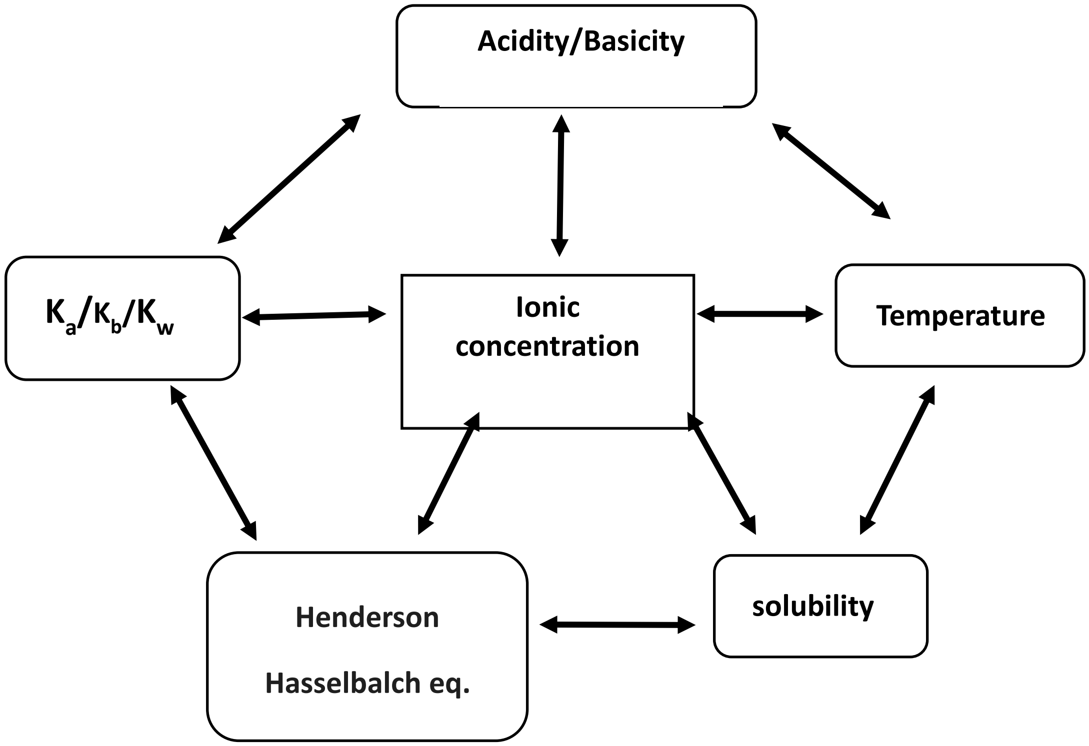

Figure 9: Systemic diagram to explain the ionic concentration

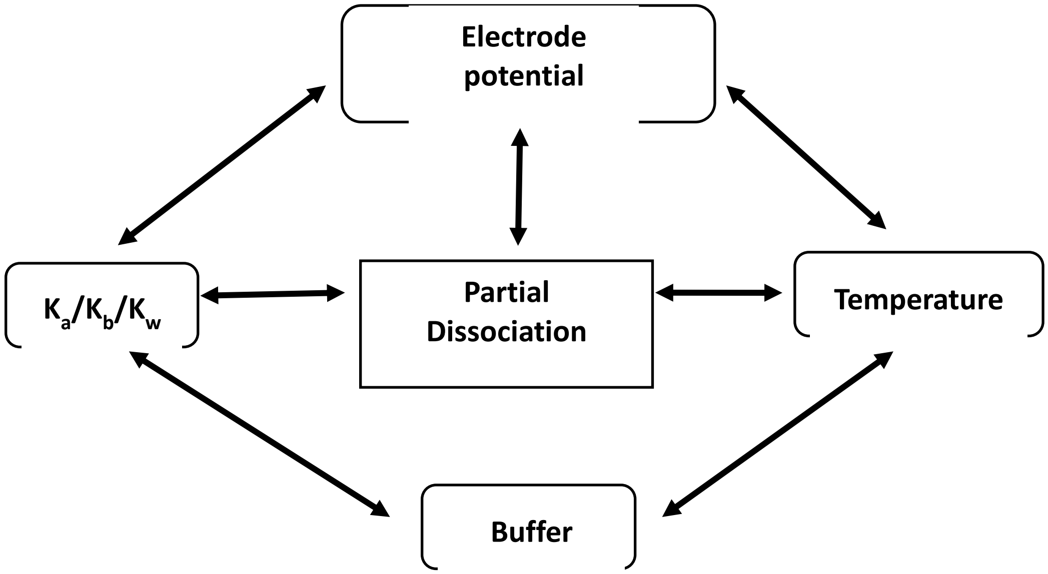

Figure 10: Systemic diagram to explain the partial dissociation

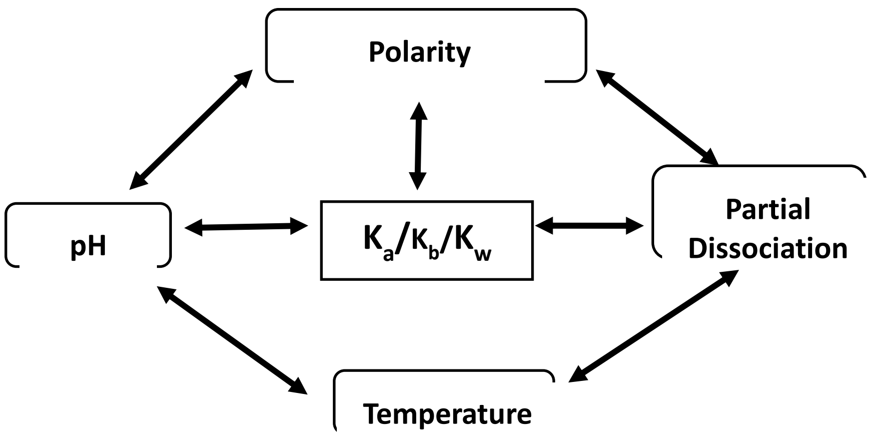

Figure 11: Systemic diagram to explain the $K_a/K_b/K_w$

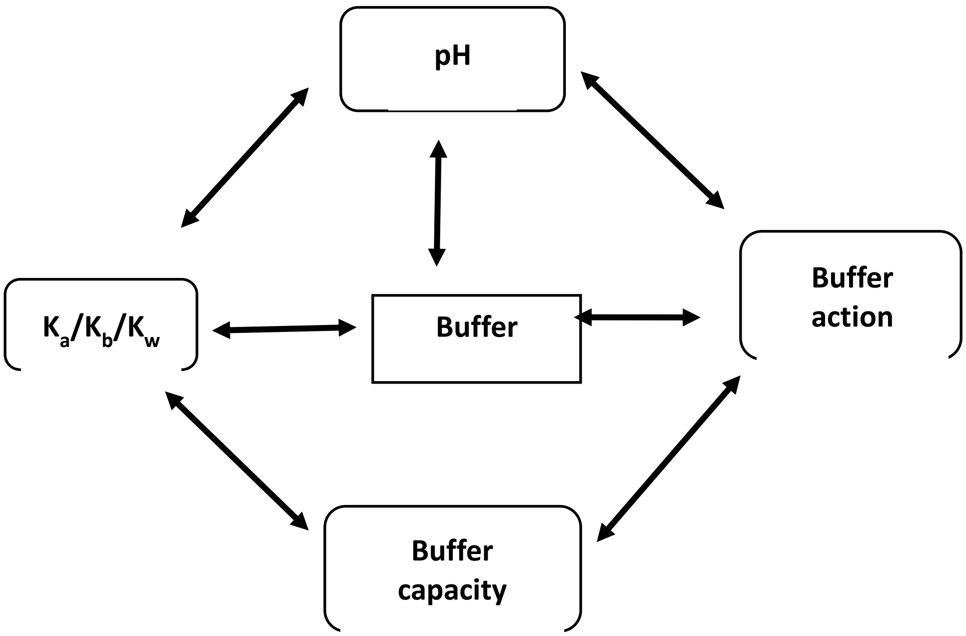

Figure 12: Systemic diagram to explain the buffer at its relation with other factors

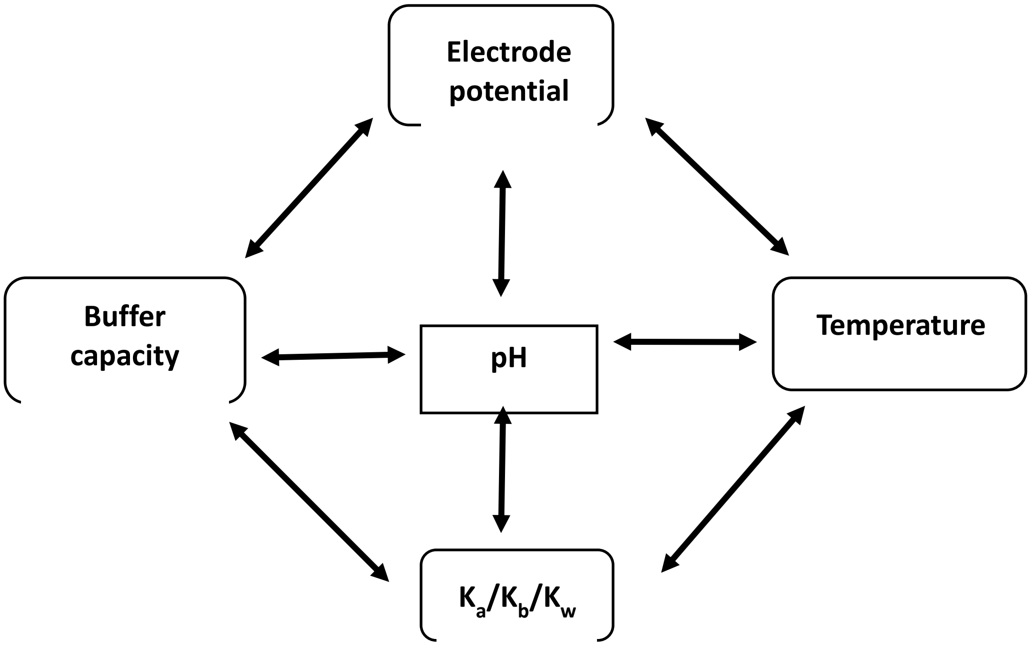

Figure 13: Systemic diagram to explain the pH

SUMMARY

The need of systemic method approach is necessary for better and deep-interactive discussion of the general chemistry concepts. Through the understanding of various linkages in SD0 stepwise, SDf can be achieved. The interconnection of different systemic diagrams (figure 11) gives justification to the topic. In this model lesson connectivity of various general chemistry concepts to the solution have been deciphered (Figure 14). Hence, this model lesson will pave the more meaningful way to understand about the fundamental concept of chemistry i.e., “solutions”.

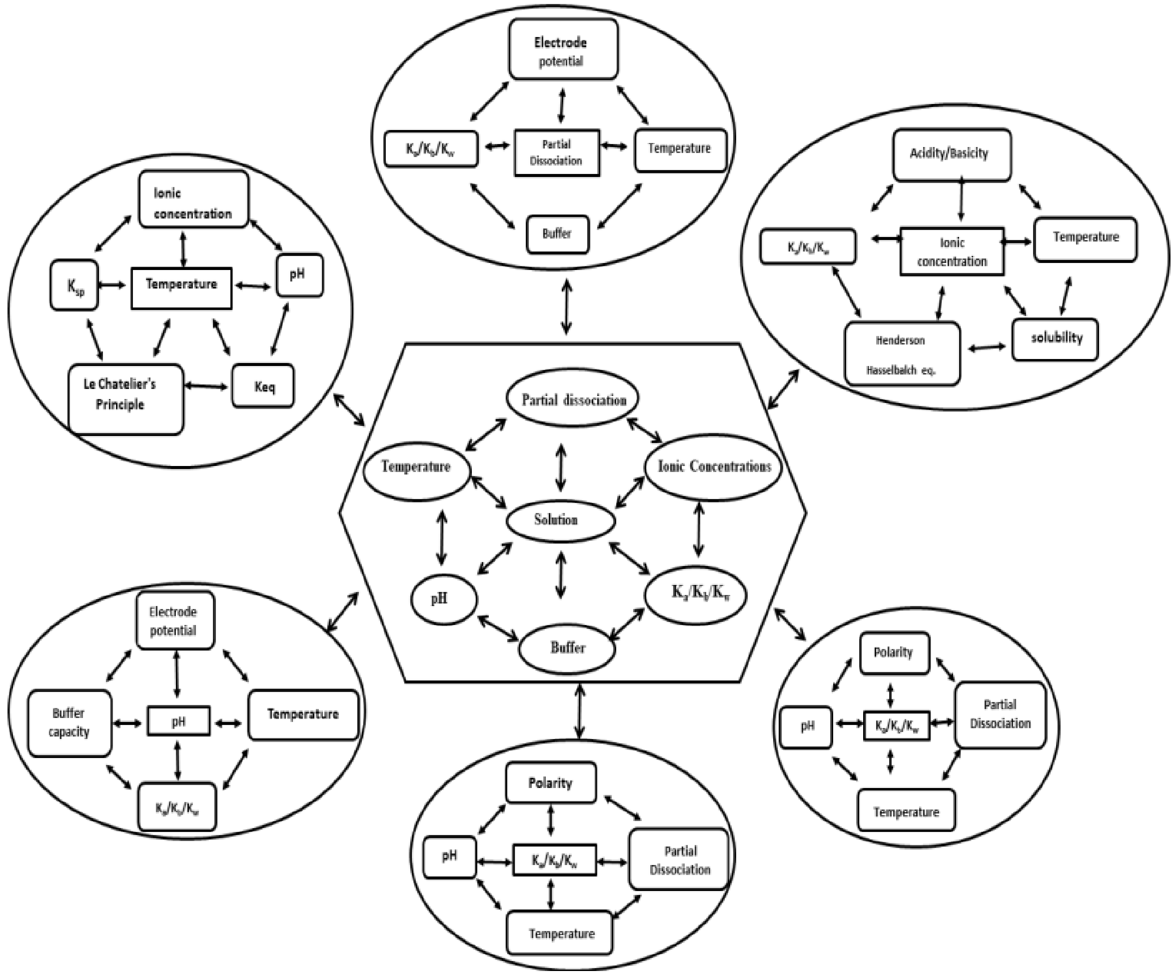

Figure 14: Single display of final systemic diagram and various concepts

This model lesson has been designed considering the importance of *conceptual knowledge*. For instance, the concept of pH will elaborate the chemical condition of the solution, behavior of species during a chemical reaction, and then if the pH is the requirement, the application and importance of buffer will be revealed to learner.

Selection of specific pH- buffer helps the learner to learn about the world of buffers, in terms of types, buffer action, buffer capacity, conjugate acid, conjugate base, and other physical factors that affect the buffer solutions and so on. This pH and buffer essentials will be helpful not only in chemistry, but the learner will be able to apply these in various other fields of sciences too, such as in biological systems, in agriculture, food science and pharmaceutical sciences etc.

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CHEMISTRY TEACHERS' OPINIONS ON AND ATTITUDES TO THE IMPLEMENTATION OF SYSTEMIC TASKS INTO TEACHING IN SLOVAKIA

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ABSTRACT

The goal of the research was to determine the opinions and attitudes of chemistry teachers regarding systemic tasks and their implementation into organic chemistry teaching at grammar schools. To achieve this goal, a set of work sheets with systemic tasks were created for the following topics in organic chemistry: Introduction to Organic Chemistry, Hydrocarbons, Hydrocarbon Derivates, Hydroxyderivatives and Carboxylic acids and their derivatives. This paper demonstrates examples of the systemic tasks that have been created to develop higher-order cognitive processes. 89 teachers used these tasks to teach 2136 second-year grammar school students over the course of two years (2019–2021). A questionnaire designed by the authors was used to collect the opinions of the teachers who participated in the presented research regarding the pros and cons of teaching using systemic tasks from the viewpoints of student motivation, deeper understanding of organic chemistry, students' ability to tackle such tasks, skill development, and time requirements. *[African Journal of Chemical Education—AJCE 13(4), December 2023]*

INTRODUCTION

Systemic Approach to Teaching and Learning (SATL) is a teaching strategy developed over the last two decades [1-7]. It aims to transform mechanical learning into learning with deep understanding [8]. This goal can be achieved through the development of systemic thinking by means of system-oriented learning tasks [9]. These tasks used closed schemes, also referred to as systemic diagrams, in which concepts are directly or indirectly linked to create a closed conceptual structure. Students are required to analyse, create, or complete a system diagram by employing systemic thinking to develop important skills such as the ability to distinguish concepts, identify relationships, analyse the system to identify basic components (concepts and links), and synthesize them into interconnected subsystems forming the whole [10]. Students do not learn isolated concepts by heart – they connect these concepts with facts in a logical context instead [11].

Many studies [12-16] dealing with science education emphasize the fact that systemic thinking is a particularly important higher-order cognitive skill, and it should be supported and developed during classes.

To address the requirement for improving students' creative and critical thinking in teaching, it is necessary to focus on developing the higher-order cognitive processes through suitable educational activities [17-18].

A number of studies [2, 10, 19-20] have addressed ideas for systemic tasks in organic chemistry and their implementation in teaching aimed at the development of systemic thinking skills in high school students. Their results confirm that teaching organic chemistry using systemic tasks really is more efficient than traditional teaching methods. According to [2, 19-20], SATL implementation significantly improved students' performance in high-school organic chemistry. These results also show that the SATL approach improved meaningful learning in organic chemistry, thus facilitating greater cognitive efficiency.

The affective surveys [2] indicate that students have a positive perception of the SATL approach. The studies published so far indicate that teachers' opinions on this teaching method have not yet been addressed.

The SATL approach is a new thing for chemistry teachers at Slovak schools, which is why the research presented in this paper aimed to identify their opinions on and attitudes to its implementation in the teaching of organic chemistry. To achieve this goal, worksheets with systemic tasks in organic chemistry focused on higher-order cognitive processes were created. Chemistry teachers implemented them in teaching grammar school chemistry and subsequently took a survey allowing the research team to identify their opinions on and attitudes to these tools.

Research Problem

Slovakia is one of the countries where teacher-centered methods still prevail [21-22].

In the long term, it reflects in the OECD PISA results (Programme for International Student Assessment). The OECD PISA results indicate that Slovak students acquire a large quantity of knowledge including theory and are able to formulate brief explanations and make decisions, but they find it difficult to study scientific phenomena independently and contextually, build hypothesis, seek and propose solutions, interpret findings, draw conclusions, and support their ideas with arguments [23]. Slovak students find it difficult to deal with tasks that require higher-order cognitive processes such as analysis, evaluation, and creativity [24]. As indicated by [3], systemic tasks have the potential to develop and verify higher-order cognitive processes such as analysis, synthesis, and evaluation as specified in Bloom's taxonomy [25-26].

Therefore, inclusion of systemic tasks into teaching organic chemistry at grammar schools can be considered a suitable way to shift from memorisation to meaningful learning with deep understanding. However, teachers must take the first step, become familiar with these types of tasks and learn how to use them in teaching.

Research Aim and Research Questions

The goal of this research was to identify the opinions and attitudes of chemistry teachers regarding systemic tasks and their implementation into organic chemistry teaching at grammar schools.

This research addressed the following research questions:

1. To what extent do the systemic task worksheets comply with the content and performance standards of Chemistry as an academic subject according to the State Educational Programme (SEP) for grammar schools?
2. What are the pros of the implementation of systemic tasks into teaching?
3. Which skills of the students are developed by systemic tasks?
4. What are the cons of implementation of systemic tasks into teaching?

METHODOLOGY

Research Design

In this research the questionnaire design was employed. Questionnaires are widely used in educational research [27-29]. [30] explained that their popularity may be explained by the benefits they have for gathering qualitative research data compared to other qualitative methods, such as interviews or focus groups (convenience, cost, standardization, ‘self-administered’, validity, reliability, anonymity, and ‘scalability’). The questions used within a questionnaire should provide answers to research questions. Attitudinal questions aim to find and explore respondent’s attitudes or beliefs about a particular subject [31-32]. This type of questions aims to identify respondent’s attitude to the subject matter. Closed questions are typically used when the respondent can provide a specific answer or when there are many ways to answer a question, and the researcher has a pre-defined set of answers [33]. Figure 1 presents the phases of this research.

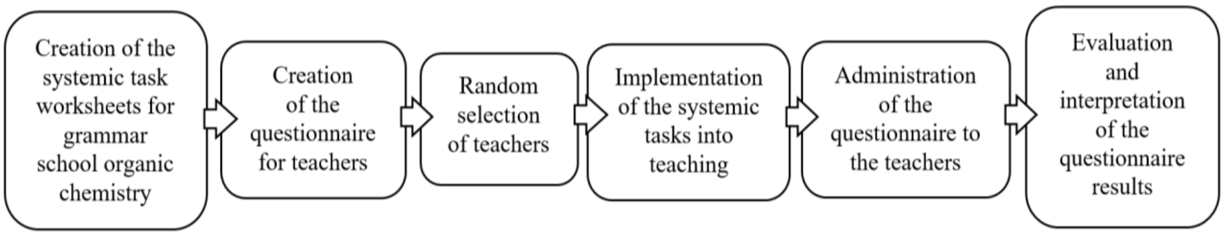


Figure 1: Phases of the research.

Preparation of Experimental Processing Tools and Measurements

The preparation of the experimental processing tools involved the following steps:

1. Choosing the educational content

In Slovakia, organic chemistry as a subject matter is taught mostly in the 2nd year of 4-year grammar schools or 6th year of 8-year grammar schools. The State Educational Programme for grammar schools [34], part ‘Chemistry as an academic subject’, points out that it is important to emphasize the context, i.e., students are supposed to understand how the structure of organic substances is linked to their properties as well as reactivity principles and the most important reactions. Reactivity of organic compounds is one of the most difficult parts of organic chemistry study.

2. Preparation of systemic task worksheets for organic chemistry

In accordance with the content and performance standards of Chemistry as an academic subject for grammar schools [34], a set of work sheets with systemic tasks were created for the following topics in organic chemistry: Introduction to Organic Chemistry, Hydrocarbons, Hydrocarbon Derivates, Hydroxyderivatives and Carboxylic acids and their derivatives. This worksheet contained systemic tasks focused on the following subject matters: types of chemical reactions and organic compounds, relationships between hydrocarbons and their derivatives, hydroxyderivatives of hydrocarbons and their reactivity, carboxylic acids, and their derivatives with emphasis on reaction conditions/reagents. The systemic tasks created by the research team enhance students' ability to work with specialised texts and schemes, analyse information, and synthesize them. They also help develop students' ability to work in pairs or groups, discuss, communicate, and provide arguments.

From the viewpoint of cognitive processes according to revised Bloom's taxonomy (hereinafter RBT) [26], systemic tasks in these worksheets are focused on higher-order cognitive operations such as:

- the ability to apply knowledge in new, specific situations,
- the ability to analyse or synthesize individual parts of a system diagram,
- the ability to compare and evaluate whether the system diagrams provided are correct.

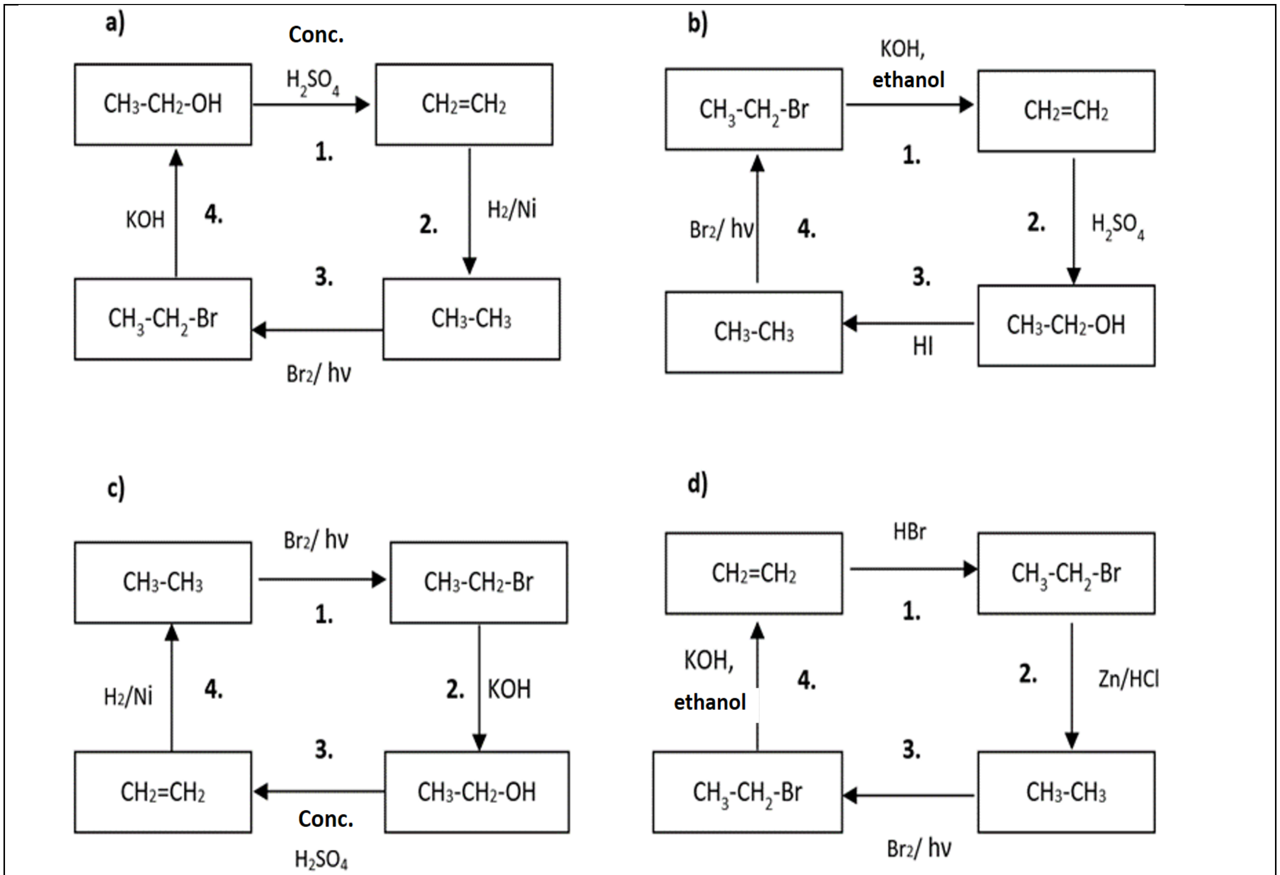
However, it is necessary to point out that the diagrams in the systemic tasks only contain schematic (incomplete) equations, therefore by-products are sometimes not supposed to be written down.

All worksheets were created in cooperation with teachers, pilot-tested, and optimised. In the creation of the systemic tasks, the authors drew on relevant publications [6, 9, 11]. Some tasks have already been published in previous research papers; others were created from scratch in cooperation with teachers.

Table 1 shows examples of systemic tasks focused on higher-order cognitive processes used in the worksheets created for organic chemistry.

Table 1: Examples of systemic tasks in organic chemistry assigned to the respective dimensions of knowledge and cognitive processes according to RBT.

Task 1 – Systemic True False **Dimension of knowledge/cognitive process:** conceptual knowledge/analysis Determine which system diagram shows the course of chemical reactions in this order: substitution – substitution – elimination – addition.



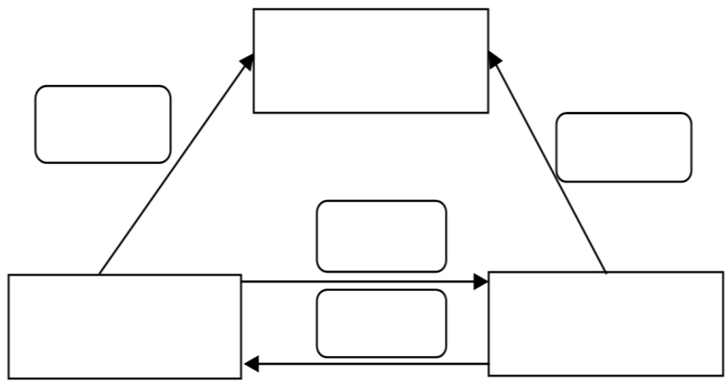
Students are supposed to analyse all answers and pick the correct one. This task can be expanded by asking the students to explain their reasoning.

Solution: Systemic diagram c) is correct.

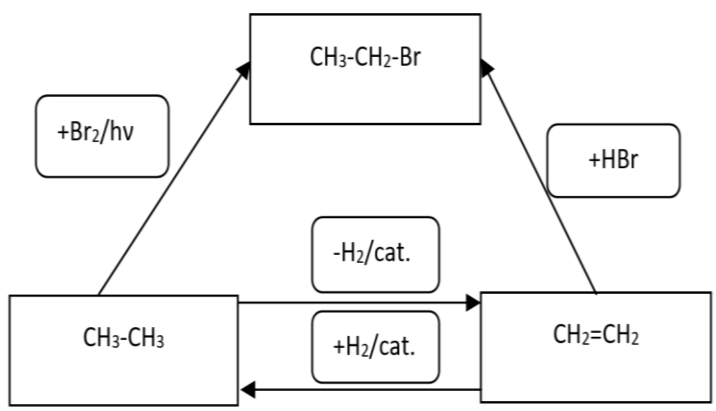
Task 2 – Systemic Matching

Dimension of knowledge/cognitive process: conceptual knowledge/analysis

Link compounds in column A to reaction conditions/reagents in column B and note down the system diagram into column C.

A	C	B
$CH_2=CH_2$ CH_3-CH_3 CH_3-CH_2-Br		$+Br_2/hv$ $+HBr$ $-H_2/cat.$ $+H_2/cat.$

Solution:

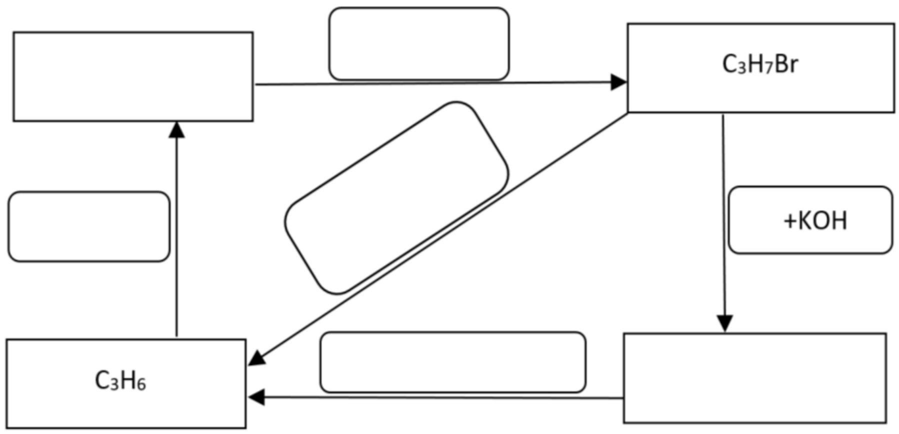
A	C	B
$CH_2=CH_2$ CH_3-CH_3 CH_3-CH_2-Br		$+Br_2/hv$ $+HBr$ $-H_2/cat.$ $+H_2/cat.$

This task can also be used for assessment, points can be assigned for correct links between the compounds and reaction conditions/reagents in the diagram.

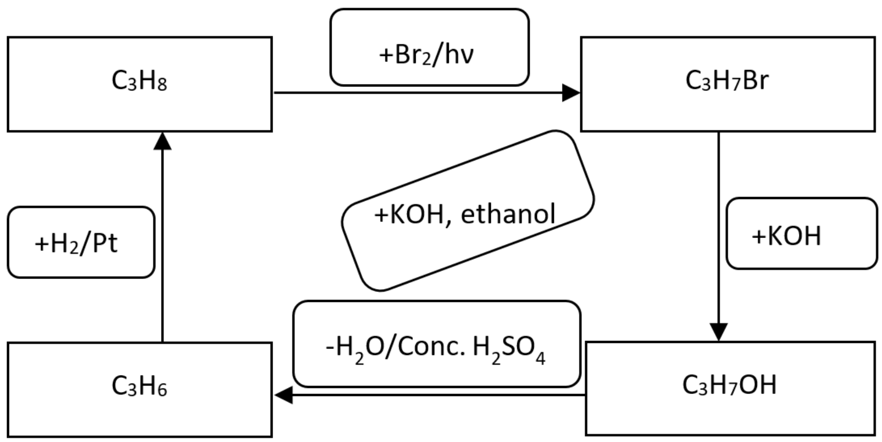
Task 3 – Systemic Sequencing, Completion

Dimension of knowledge/cognitive process: procedural knowledge/analysis

Categorise the organic compounds C_3H_8 and C_3H_7OH and proceed to fill in the reaction conditions/reagents into the system diagram below.



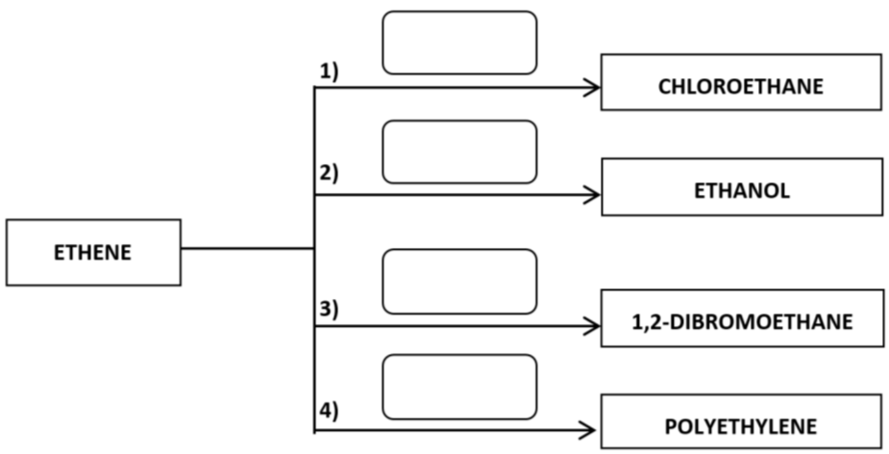
Solution:



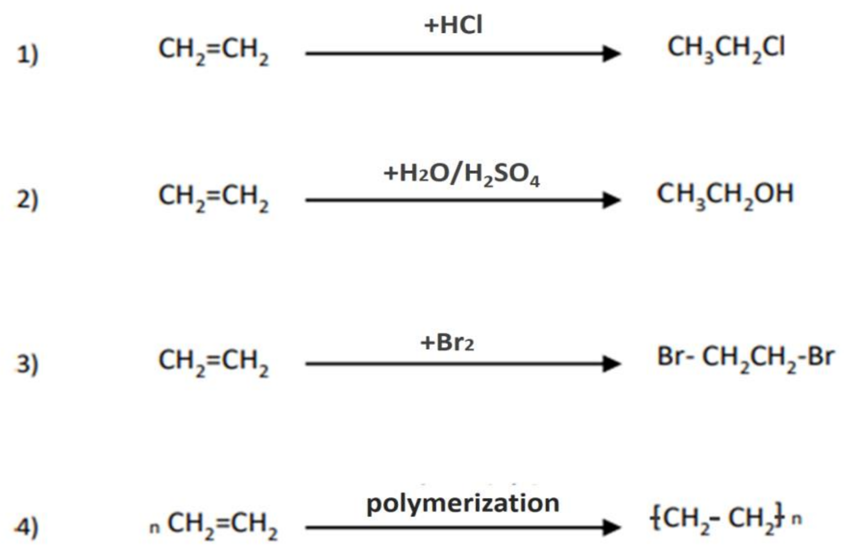
Task 4 – Systemic Synthetic-Analytic

Dimension of knowledge/cognitive process: procedural knowledge/analysis

Fill in the correct reaction conditions/reagents into the diagram and write down the respective reactions using chemical equations. Name the reaction No. 4.



Solution:



Worksheets contained more difficult tasks consisting of multiple types of systemic tasks as well. For example, the systemic task for the topic Carboxylic Acids and Their Derivatives contained partial tasks focused on completion, analysis, and synthesis. This task is suitable for group work.

Task 5 – Completion, Systemic Synthetic-Analytic

Dimension of knowledge/cognitive process: procedural knowledge/analysis, evaluation

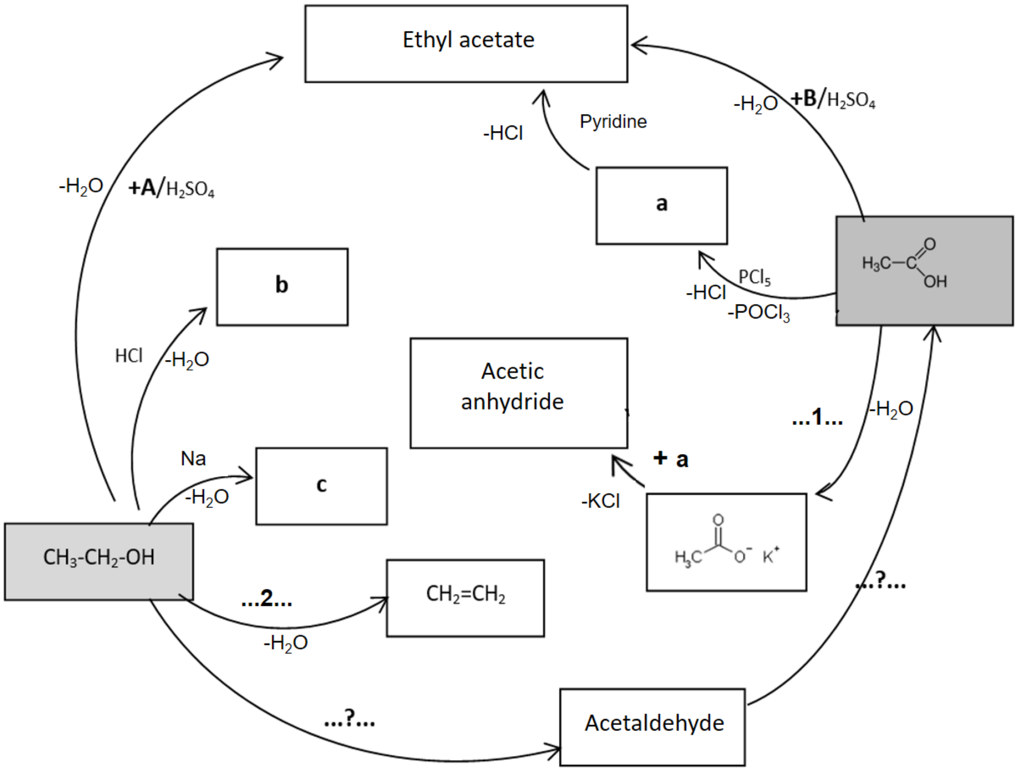
The diagram below shows reaction relationships between hydrocarbons, hydrocarbon derivatives, carboxylic acids, and their derivatives. Fill in:

A. names of the products (a–c)

B. reaction conditions (1–2)

C. names of the reactants (A–B)

D. type of the reaction (?)



Solution:

a – Acetyl chloride, b – Ethyl chloride/Chloroethane, c – Sodium ethoxide (Sodium ethanolate)

1 – KOH, 2 – Conc. H_2SO_4, heat

A – *Acetic acid*, B – Ethanol

? – Oxidation

Tasks focused on the development of metacognitive skills

Worksheets end with tasks focused on the development of students' metacognitive skills. The experience indicates that it is often difficult for students to evaluate their own performance verbally. However, a self-assessment card as a formative assessment tool allows them to evaluate their own understanding of the subject matter. It provides the criteria that help students subjectively describe their level of knowledge and skills, which they intuitively feel, but are unable to express verbally [35].

Students' answers in the self-assessment cards show which knowledge students have and where assistance is still needed with systemic tasks, thus providing both the teacher and students with feedback. Based on this feedback, the teacher can adjust and plan further implementation of systemic tasks in teaching.

Below are examples of self-assessment cards for the topics Hydrocarbons (Table 2) and Carboxylic Acids (Table 3) filled by students.

Table 2: An example of a self-assessment card for the topic Hydrocarbons filled by a student (with excellent academic record).

Put in a cross to indicate how much you agree with the respective statement	**Yes without assistance**	**Partially, with assistance**	**Not yet**
I can complete system diagrams using formulas and reaction conditions/reagents, which correctly express the reactions between alkanes, alkenes, and alkynes.	x		
I can use system diagrams to **write down** chemical equations expressing the reactions between alkanes, alkenes, and alkynes.	x		
I can create a system diagram based on the organic substances/compounds and reaction conditions/reagents provided.		x	

Table 3: An example of a self-assessment card for the topic Carboxylic Acids filled by a student (with average academic record).

Put in a cross to indicate how much you agree with the respective statement	**On my own**	**With some assistance**	**With major assistance**
I can write down the formulas of important carboxylic acids.	x		
I can add reaction conditions/reagents for the reactions during the preparation of carboxylic acids.	x		
I can write down the products of carboxylic acid reactions and name them.		x	
I can analyse the system diagram of chemical reactions between alcohols and carboxylic acids, add the reaction conditions, products, and type of reaction.			x
I can provide arguments and justify the correctness of my claims.			x

Self-assessment cards allow students to track their own learning processes, evaluate their efficiency, and if necessary, modify the learning strategies.

Research Tool

Teachers' opinions on and attitudes to systemic tasks in the worksheets after teaching organic chemistry with them were collected via an electronic feedback questionnaire developed by the authors. The questionnaire consisted of two modules. Module A focused on the basic information about the respondents/teachers. Module B included 14 items divided into three areas in line with the research questions. Teachers expressed their opinions on and attitudes to individual questionnaire items using a three-point scale ("yes," "I do not know", "no"). The questionnaire can be comfortably completed in 25 minutes.

To ensure that the questionnaire items were valid, it was analysed by an associate professor at the Department of Chemistry Education to verify that the items were relevant to the objectives of the research. The reliability of the questionnaire was calculated using the Cronbach's alpha [36]; $\alpha=0.783$ is an acceptable reliability coefficient.

Research Sample

The research sample consisted of 89 grammar school chemistry teachers and data were collected over two academic years (2019–2021). The grammar schools were selected randomly and covered the whole country. All teachers involved in this research participated in the IT Academy –

Education for the 21st Century project (2016–2021, https://itakademia.sk/) and expressed their interest in implementing the systemic task worksheets developed by the authors in teaching. A total of 2136 second-year grammar school students participated in the research. During the COVID-19 pandemic, approx. 50% teachers used the worksheets for online teaching (mostly via MS Teams).

Ethical Consideration

All teachers were informed about the objectives of the research, and their participation was voluntary and anonymous. Online consent with the participation in this research was obtained from the teachers.

Data Analysis

The questionnaires were administered online, collected, and analysed using the Statistical Package for Social Science (SPSS) version 18 [37]. Basic data evaluation was performed. The items were analyzed according to the questionnaire areas as well as separately.

RESULTS

In this part of the paper, the results of the questionnaire focused on teachers' opinions on and attitudes to the implementation of systemic tasks in teaching will be presented (Tables 4–6).

1. **To what extent do the systemic task worksheets comply with the content and performance standards of Chemistry as an academic subject according to the State Educational Program for grammar schools?**

Table 4: Teachers' opinions on and attitudes to systemic tasks in the worksheets.

Teacher responses [%]	**Yes**	**I do not know**	**No**
1) Systemic tasks enhance and consolidate students' knowledge in accordance with the goals specified in the SEP for grammar schools.	87.64	12.36	0.00
2) Systemic tasks have been created professionally, are clear, and comprehensible.	89.89	10.11	0.00
3) The order of the systemic tasks in the worksheets is consistent with their increasing difficulty.	88.76	11.24	0.00
4) The systemic tasks are variable (completion, matching, synthesis, analysis, synthetic-analytic, sequencing, true-false).	88.76	11.24	0.00

Note: No negative response was recorded on the three-point scale.

2. **What are the pros of the implementation of systemic tasks into teaching and which skills do they develop in students?**

Table 5: Chemistry teachers' opinions on and attitudes to the implementation of systemic tasks into teaching – pros.

Teacher responses [%]	**Yes**	**I do not know**	**No**

5) Systemic tasks connect the existing knowledge to the new one, which helps students understand the context, i.e., consolidation and learning with deep understanding is achieved.	89.89	10.11	0.00
6) Unlike traditional tasks, systemic tasks develop higher-order cognitive processes such as analysis or evaluation (according to RBT).	84.27	15.73	0.00
7) Systemic tasks allow for the identification of students' misconceptions.	82.02	17.98	0.00
8) Systemic tasks develop the following skills:			
- critical thinking	88.76	11.24	0.00
- argumentation	88.76	11.24	0.00
- group cooperation	84.27	15.73	0.00
- the ability to create, analyse, and complete system diagrams	89.89	10.11	0.00
- result interpretation	82.02	17.98	0.00
- drawing conclusions and generalisations.	86.51	13.49	0.00
9) Students are interested in doing systemic tasks.	78.65	13.48	7.87
10) I plan to continue using these types of tasks in teaching.	88.76	11.24	0.00

3. What are the cons of the implementation of systemic tasks into teaching?

Table 6: Chemistry teachers' opinions on and attitudes to the implementation of systemic tasks into teaching – cons.

Teacher responses [%]	Yes	I do not know	No
11) Time requirements – lack of time to complete systemic tasks (mainly during distance teaching).	40.44	10.11	49.45
12) Lack of methodological material for more topics.	73.03	11.24	15.73
13) Insufficient skills to implement systemic tasks into teaching.	41.57	11.24	47.19
14) Students have insufficient theoretical knowledge to deal with systemic tasks.	60.67	10.11	29.22

DISCUSSION

In this research, the evaluation of teachers' opinions on the positive and problematic aspects of the systemic tasks implementation into teaching were presented.

According to 87.64% of teachers, the systemic task worksheets provided enhance and consolidate students' knowledge in accordance with the goals specified in the Chemistry SEP for grammar schools [34].

88.76% of teachers perceived the increasing difficulty of systemic tasks in the worksheets as positive as it encouraged students to go on. If they correctly completed the initial simpler tasks, they were more motivated to consider the more difficult ones, which is in line with RBT goals [26].

Systemic tasks connect the existing knowledge to the new one, which helps students understand the context, consolidate their knowledge, and learn with deep understanding (according to 89.89% teachers). Similarly, [2, 6, 38-39] opined that SATL-based learning is an active process where learners are encouraged to discover principles, concepts, and facts, and arrange them in a systemic relationship. SATL increases students' ability to learn the subject matter in a broader context.

The systemic task worksheets help students develop higher-order cognitive processes such as analysis, synthesis, and evaluation (according to 84.27% of the teachers). Systemics emphasizes the development of higher-order cognitive skills [6, 40] as defined by Bloom [25-26]. Abilities such as formulating questions and arguments, drawing conclusions, critical and systemic thinking also pertain to the higher-order cognitive skills [41-43]. Most teachers evaluated the development of these skills via systemic tasks positively (Table 5). SATL allows for important educational interactions among students or students – teacher [6], which facilitates the development of communication skills (according to 84.27% teachers).

Dealing with systemic tasks helps students develop science literacy [44-45]. 82.02% teachers believe that systemic tasks allow for the identification of students' misconceptions stemming from incorrect understanding of the previous educational content, which influences their ability to comprehend the basics of organic chemistry. Therefore, the construction of mental models is an important goal of learning and teaching organic chemistry. In this case, the risk that the student will inadvertently remember incorrect answers from single-choice test questions is removed [46].

It must be pointed out that students involved in this research lacked previous knowledge about e.g., nomenclature of the organic compounds, determining the types of chemical reactions or reaction conditions/reagents, which affected their ability to complete the tasks. The available research [47-48] has also identified certain problems with the ability to complete the systemic tasks due to insufficient understanding of the relationship between the structure and properties of organic compounds.

Concerning the cons of using systemic tasks in teaching, teachers mostly complained about the time requirements, the lack of worksheets for other topics, and the necessity to receive training beforehand (Table 6).

Slovak experience is consistent with other countries in which teachers always complain about the lack of time when it comes to the implementation of teaching methods focused on active student work [49].

The traditional way of teaching focused on explaining the subject matter is less time-consuming, but the knowledge developed by students is often superficial and without deep understanding. On the other hand, active learning can help students discover new ways to tackle complex concepts and problems. It promotes creativity and develops problem-solving skills, which will be highly useful to students in their future life and careers [50-51].

Even teachers with differing experience, expertise, and age can be trained to use SATL in a short time. Although the teacher training programme requires activities focused on creating SATL materials [10], the SATL methods can be used by any teacher who undergoes the training and receives materials.

CONCLUSION

The presented research showed that the systemic tasks designed by the authors are fully implementable in teaching organic chemistry in the 2nd year of 4-year grammar schools or 6th year of 8-year grammar schools. They can also be used for revision during the seminars taken in the final year. Teachers do not need extensive training.

Teachers implemented the systemic tasks into teaching with the aim to motivate students and provide them with feedback to improve their learning process. Therefore, systemic tasks can also be considered a type of formative assessment. Some teachers used the systemic tasks for the purpose of summative assessment, i.e., they assigned points and calculated grades.

Systemic tasks require students to create, analyse, and complete system diagrams, which helps them develop higher-order cognitive processes such as analysis, synthesis, and evaluation, which in turns, promotes deep understanding.

Completing systemic tasks develops critical and systemic thinking as well as skills such as the ability to formulate questions and arguments or draw conclusions – which memorisation does not.

Systemic tasks help identify the reasons why students are unable to complete them by identifying their misconceptions stemming from the incorrect understanding of the previous educational content.

It is also efficient to use self-assessment cards after the completion of systemic tasks to let students analyse the correctness of their answers.

Both teachers and students want to continue working with systemic tasks in more topics (e.g., biochemistry) and even other academic subjects.

Teachers also recommend short training using the existing materials and systemic tasks before using them in teaching or creating them.

ACKNOWLEDGEMENTS

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SYSTEMIC ASSESSMENT QUESTIONS FOR SYSTEMS THINKING DEVELOPMENT AND EVALUATION IN ORGANIC CHEMISTRY DOMAIN: A REVIEW OF APPLICATIONS AND FUTURE PROSPECTIVES

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ABSTRACT

The systems thinking is one of the fundamental 21st century thinking skills that our students should develop. Therefore, the value of systems thinking in chemistry education is increasingly recognized through developing efficient evaluation and/or instructional tools. This review investigated how the systems thinking skills were developed and evaluated in organic chemistry classes with the application of systemic approach to teaching and learning, SATL, and more precisely systemic assessment questions, SAQs. The empirical peer-reviewed articles indexed in SCOPUS database were analyzed. In order to analyze and compare included studies, four descriptors were formulated, and qualitative content analysis approach was further used. The results indicated that analyzed studies used DSRP (distinctions, systems, relations, perspectives) model in order to develop scoring rubric for assessing students' systems thinking skills after solving SAQs. SAQs were found to be efficient assessment tools with acceptable psychometric properties such as good validity and reliability. In the newest studies, SAQs were characterized as suitable instructional tools for enhancing students' systems thinking skills. The analyzed studies included additional factors that could be related to the construct of systems thinking, such as meaningful understanding of chemistry concepts and/or students' gender. At the end, the areas that need further investigation or improvement were highlighted. *[African Journal of Chemical Education—AJCE 13(4), December 2023]*

INTRODUCTION

The problems of „systems“ were ancient and had been known for many centuries, but they remained philosophical and did not become „science“ because of their complexity (von Berttalanffy [1, p. 411]).

It is well known fact that chemistry learned in schools is increasingly complex and abstract subject [2], often loaded with a large amount of information [3] that nowedays should be mastered in the environment of dynamic and fast changing world. Surly, this makes solving chemistry problems more demanding. The great power in solving complex problems that students cannot solve using conventional reductionist thinking has the concept of *systems thinking* [4] that is becoming more and more popular in science/chemistry education [5].

The brilliant, fundamental roots of the systems thinking can be found in *General Systems Theory* that has been firstly formulated in 1930's by von Berttalanffy [1]. A logico-mathematical General Systems Theory has been introduced within biological systems, but it is perfectly applicable in chemistry context too. Von Berttalanffy used mathematical descriptions of main systems properties such as wholeness, sum, growth, centralization, hierarchical order, etc. This theory has used the Aristotelian dictum “the whole is more than its parts” as investigation of the single parts and processes cannot provide a complete explanation and/or understanding of the system [1]. The properties of the system are not those that belong to the individual parts/components since the status of one component affects the status of other components of the system [6]. The parts/components need to work together in order the whole/system functions successfully [7]. Therefore, it could be said that the fundamental characteristic of the system is its *organization*, and to be able to understand the organized whole, we must know both its parts and relationships between them, i.e. interrelations between many but not infinitely many parts/components.

According to this, Salisbury [8] defined *systems thinking* as the ability to structure the relationships between the components in the system in an effective way. The person must think about all the components and the relationships that exist within a system, in order to effectively structure the relationships. To simplify this definition, it could be said that systems thinking is a way of thinking for a person to understand the system. However, systems thinking does not refer to the breaking down a system into its parts/components. Instead, systems thinking focuses on how the components act together in the networks, interactions, and interconnectedness [7].

Diverse interpretations of systems thinking lead to the diversity of systems approaches [9] that have offered not only the theoretical perspective, but also methodology to deal with the systems thinking [5]. The systems approaches will be considered in the following “Literature framework”.

LITERATURE FRAMEWORK

Systems Approaches: The DSRP Model

Despite diversities, in all systems approaches, the central construct is the term *system* that has been introduced earlier in this paper. It is obvious that the main building blocks of the system are not the parts/components but the relationships between them [9]. Why? Because components are not always clearly defined and often, they can be recognized through the many associations with other overlapping components [10]. In order to explain this, Cabrera and colleagues [9] proposed the four cognitive patterns that shape systems thinking: *D* (distinction), *S* (systems), *R* (relationships), *P* (perspective), or *DSRP* model. Distinction can be made between and among things and/or ideas, while things and/or ideas can be organized into the systems/wholes. The systems are made of the parts/components or/and sub-systems, between which the relationships can be made. At the end, things and ideas can be observed from the perspective of other things and ideas [9]. It is clear that these four patterns, *D*, *S*, *R*, and *P* (see Fig. 1) are in constant and dynamic interplay [11]. Therefore, systems thinking is an emergent property of the *DSRP* processing rules or cognitive patterns [9], that person needs to apply within the system of interest.

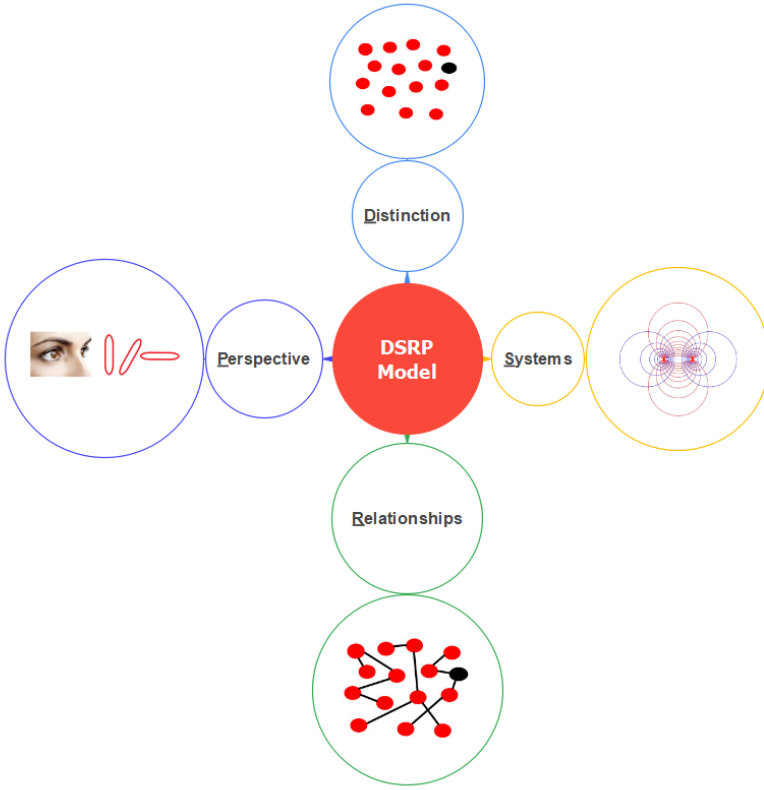

Fig. 1. Four cognitive paterns that shape systems thinking (DSRP model)

In the literature of chemistry education, there are several studies that focused on DSRP formalistic model in order to assess students' systems thinking [5, 12-16]. This model was chosen as it is suitable for the *closed systems* that possess clear boundaries that conceptually isolate the system under study [5]. The chemistry is rich of such systems that can be as complex as open systems are. In organic chemistry, there are a vast number of compounds, and each one should be observed as a concept with specific properties, such as the systematic name, functional group, molecular and structural formula, physical and chemical properties [12]. These properties *differentiate* (*DSRP*) the concept, i.e. organic compound from the others. For example, ethanoic acid is a concept that should be differentiated from the oxalic acid focusing on the number of carboxyl groups in the structures of two carboxylic acids. However, the ethanoic acid is the constituent part of the larger whole called "carboxylic acids", that is a sub-system of the larger whole called „organic compounds with oxygen", that is a sub-system of the „organic chemistry" whole, and organic chemistry is a sub-system of the *system* (DSRP) of chemistry. In order to be properly understood, the ethanoic acid should be *related* (DSRP) with appropriate concepts from the sub-systems and/or system such as, for example, calcium acetate, acetone, diethyl ether, ethanol, etc. However, the system or sub-system of these concepts could be reoriented, perhaps, by determining another focal point or *perspective* (DSRP) of the system, e.g., from the acetone perspective.

Taking into account *DSRP* model, Vachliotis and colleagues [13] developed the initial Rubric for scoring students' answers on *systemic assessment questions, SAQs,* in order to examine secondary school students' systems thinking in an organic chemistry domain. Firstly, systemic assessment questions will be introduced.

Systemic Assessment Questions

Systemic assessment questions, SAQs, have been introduced as a sub-system of *systemic diagrams* or *systemics* which have a central role within a Systemic Approach to Teaching and learning (SATL) chemistry. The SATL was created in 1998 by professors Ameen Fahmy from the Ain Shams University in Cairo, Egypt and John Lagowski from the University of Texas at Austin [17]. For the last 25 years, chemistry has been in the focus of SATL, however, this approach was applied in teaching process of a variety of subjects like biology, physics, and mathematics [18]. Taking into account the basis of the SATL, two contributing concepts should be mentioned:

- Theory of meaningful verbal learning, and
- Concept mapping technique.

In the 1960s David Ausubel developed the theoretical approach of meaningful verbal learning as a contrast to the rote or mechanical learning [19]. Ausubel has highlighted that meaningful learning occurs if students connect new concepts with those already adopted, on essential and unarbitrary way [20]. It was pointed out that meaningful learning happens through the acquisition of new meaning from presented learning material, which must be connected with the relevant mental model. Therefore, student’s mental model must possess the relevant fixed ideas to which new learning material can be connected [21]. It is well known that student’s mental model is fundamental for learning science, mathematics, and logic, as the student “manipulates” with the mental model in order to find the true answer to the difficult, complex, and abstract problems as those seen in the chemistry [22, 23]. It must be recognized that the student's mental model is incomplete and unstable at the beginning of the learning process, but with time, it continues to change, grow, and improve because new information/concepts are integrated into it [22]. On the other hand, rote or mechanical learning occurs when presented leaning material does not have an established relation with those previously learned [23], so the rote memorization is inefficient and encourages students not to think systemically.

In order to promote meaningful learning, Joseph Novak introduced concept mapping technique. Concept maps are two dimensional diagrams consisting of nodes, i.e. circles or boxes and lines or arrows. Nodes represent the main elements or concepts, while lines or arrows are labeled with linking words explaining the relationships between these elements or concepts [25]. Selected elements or concepts closed into the circles or boxes can be represented by using words and/or symbols and are arranged hierarchically where more specific concepts are placed under more general ones [26]. For example, in concept map arrangement, starting from the top of the map and moving to the lower parts, the "carboxylic acid" is placed above the concepts of "ethanoic acid" and "oxalic acid". This provides linear relationships between the set of concepts, and these features, i.e., hierarchy and linearity are the main difference between concept maps and systemic diagrams [23].

Systemic diagrams have been described as a closed system of the set of selected elements or concepts while their arrangement corresponds to the “closed concept map cluster” [17]. It is crucial to note that all possible relationships between the set of selected concepts are made clear to the students in order to provide opportunity for the students to see topic, subject, or domain globally without missing its constituent parts [17].

Later, Fahmy and Lagowski [27, 28] have created a type of questions that were philosophically compatible for the SATL in order to assess the students’ progress in learning chemistry topics [18] at secondary and tertiary levels [27, 28]. Depending on the number of the selected concepts and the size of the diagram, systemic assessment questions, SAQs, follows various geometrical shapes like triangular, quadrilateral, pentagonal, hexagonal, etc. Additionally, several types of SAQs have been proposed. In our studies, systemic synthesis questions, SSynQs, as one specific type of SAQs, were in the focus [12, 15, 21, 23, 29]. SSynQs were created to follow the structure in which the students were required to perceive defined relationships (i.e. “pyrolysis/500 ^{0}C”, see Fig. 2) and initial concept (i.e. “pentane”, see Fig. 2) in unfilled, or partially filled boxes in SSynQ, in order to identify concepts that were missing [21]. One example of SSynQ with nine concepts could be seen on Fig. 2.

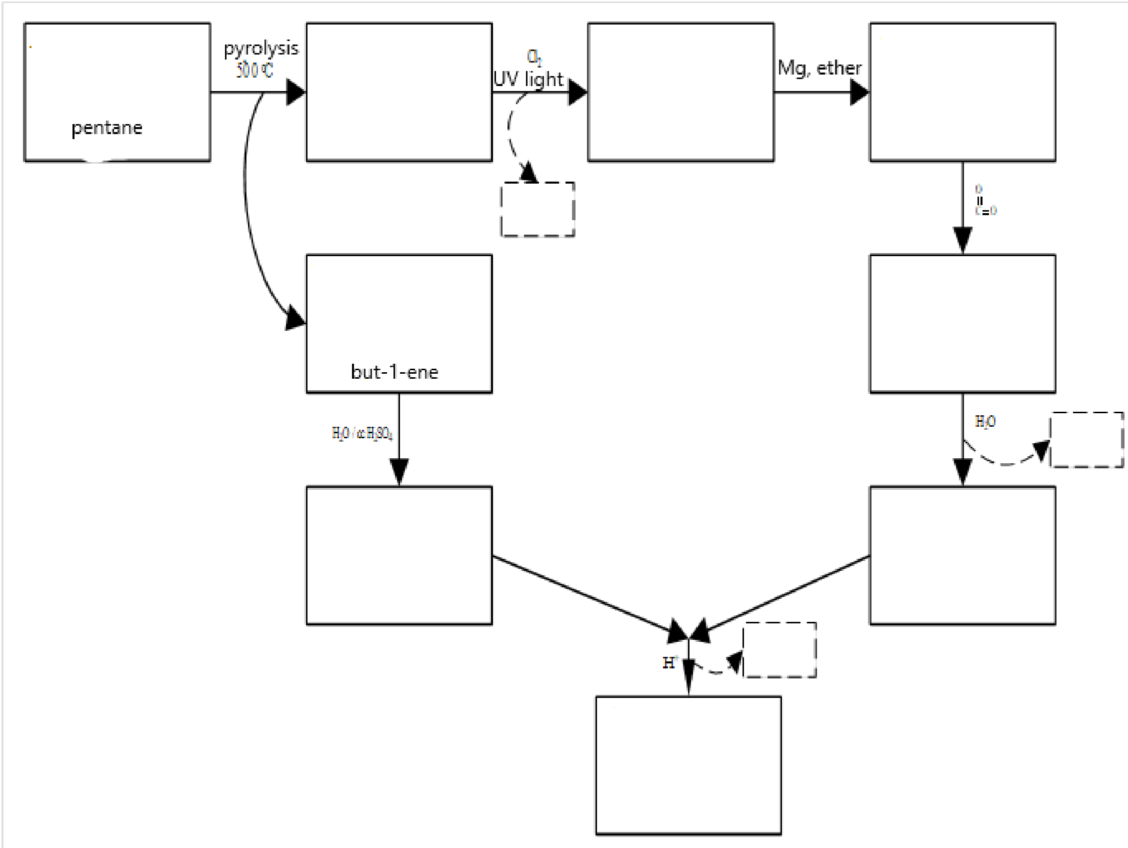

Fig. 2. SSynQ with nine concepts

The process of solving SAQs and/or SSynQs requires the following steps: (1) organize concepts, (2) define or perceive relationships between concepts, (3) synthesize concepts into sub-systems and further into coherent whole system, and (4) analyze system to the fundamental concepts

[13]. In line with this, SAQs and SSynQs were applied in the organic chemistry educational process in order to enhance and assess high school students' systems thinking skills [5, 12-15, 29]. Therefore, an appropriate Rubric for assessing students' systems thinking skills has been developed.

The Rubric for Assessing Students' Systems Thinking

The original systems thinking assessment rubric theoretically based on a formalistic system thinking conceptual model, i.e., *DSRP* model, which will be here abbreviated as STARubric was designed in order to assess Greek high school students' systems thinking using SAQs as assessment tools [13]. STARubric possessed three identification steps, where the first step, *S1*, included the identification of some individual and conceptually isolated concepts within the conceptual system. The second step, *S2*, observed two or more concepts linked together, forming a conceptual sub-system that is a part of the whole system of interest. The third step, *S3*, represented the identification and integration of all sub-systems in order to form a meaningful whole system. These three identification steps included five levels of skills that could be read in more details in the original publication [13].

In the following years, the modifications were made to the original STARubric. For example, in the later study of the same authors [5], the four steps STARubric with five scoring levels was designed. Therefore, *S1* included two levels of skills, "no connection" and "partial connection".

Furthermore, *S2*, included “sufficient connection” level, while *S3* “complex connection” level. The most desired *S4* referred to the level of skill called “system” where students were able to recognize all relevant concepts and possible relationships that form a meaningful conceptual whole. These levels of skills were made more comprehensive to capture all possible students’ responses on SAQs [5].

In the two consecutive studies [12, 15], the modified version of STARubric with three identification steps were used:

- *S1* – Identifying concepts,
- *S2* – Identifying connection between concepts,
- *S3* – Examining the connection structure.

Also, five levels of skills were translated into four systems thinking levels. Firstly, if the student provided no answer or completely irrelevant answer on SSynQ, a value of zero, *0*, is assigned (no answer, or incorrect answer level). Furthermore, if the student demonstrated skills to identify the relevant concept of a selected system or a sub-system, a value of one, *1*, is assigned. It should be explained that identified concept was unrelated with any other concept, and, as such was isolated from a system and/or a sub-system. If the student recognized a proper relationship between two concepts, a value of two, *2*, was assigned. In addition, if the student was able to organize more than two concepts and at least two processes, a value of three, *3*, was assigned. In this way, the identified concepts formed the relationships with two or more specific links. The most desired outcome of the process of the systems thinking assessment was when the student managed to interconnect all the concepts, to recognize all the sub-systems that formed the whole system of interest. Such answer on the SSynQ was evaluated with the value four, *4* [12].

To clearly illustrate how this modified version of STARubric was used to assess students' systems thinking, we will consider an example student, Joy. Looking at Fig. 3 it could be seen that Joy managed to link several concepts, i.e. organic compounds into a sub-system. He/she successfully related *pentane* with *methane* that is produced through the process of pyrolysis. Additionally, he/she related *methane* with *chloromethane* through a chlorination reaction in the presence of UV light. Therefore, Joy's answer on SSynQ would be scored with the value *3* – multiple connections were observed. It should be mentioned that Joy identified additional two concepts – *buthane-2-ol* and *ethanoic acid*, with both correct formula and name, or, in the case of ethanoic acid, only with the name (see Fig. 3). However, these concepts were not related with the other concepts, i.e. they remained isolated within this particular SSynQs.

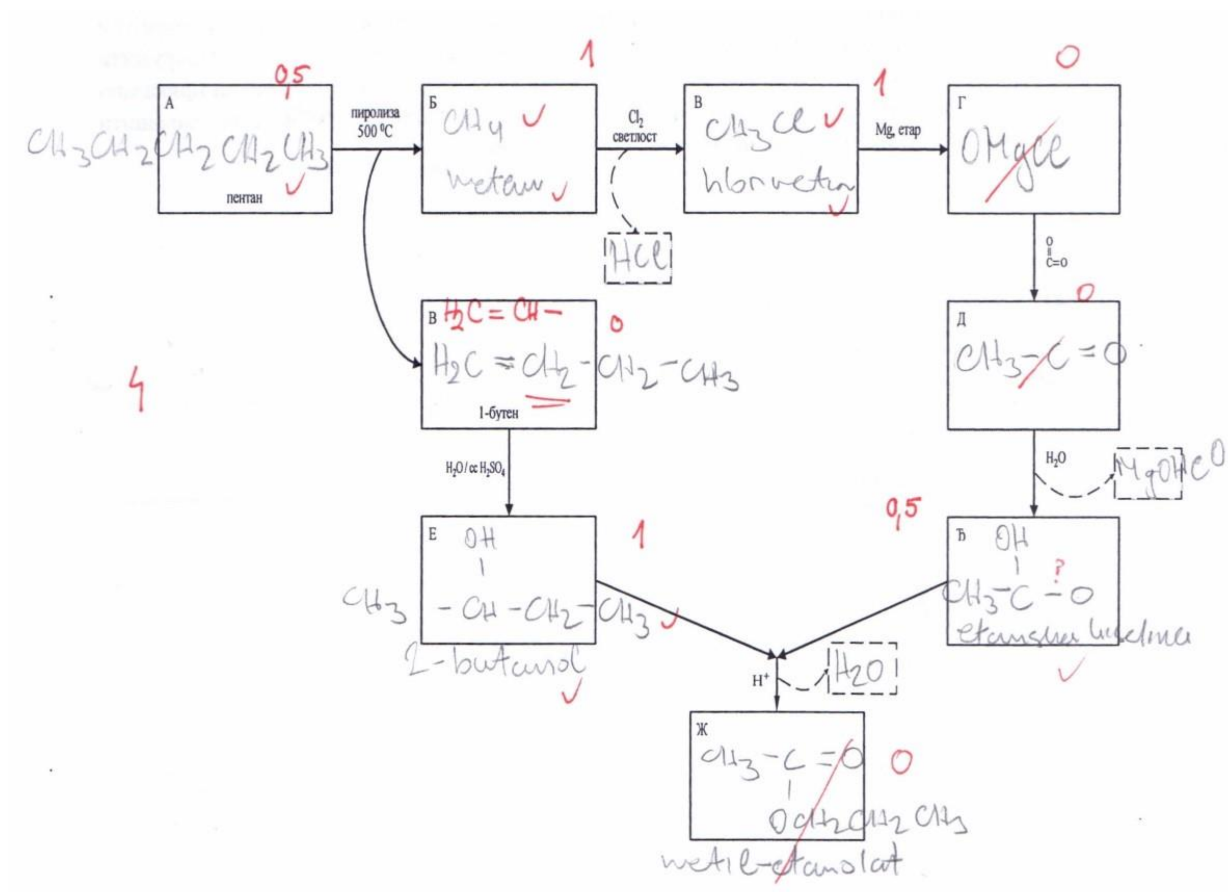

Fig. 3. The Joy's answer on SSynQ with nine concepts

METHOD

The aim of this study was not only to represent the STARubric, but also to review the articles related to students' systems thinking in chemistry education that were theoretically and methodologically related to SATL. In order to achieve this aim, the SCOPUS analytical tool was used for gathering descriptive statistics such as the year distribution of articles, publication journal, citation of articles, etc.

In the first stage of the analysis, the articles were searched on the SCOPUS database through the "systems thinking" and "chemistry" query in August 2023. Totally 118 SCOPUS-published articles in English were obtained. The first one was published in 1974, and the others between 2002 and 2023. In the second stage, we have added "SATL" in our query and 3 articles published between 2014 and 2021 were found. Two of these articles were published in the Thinking Skills and Creativity journal and one in the Research in Science Education journal. The most cited article has been published in Thinking Skills and Creativity journal in 2017 (see Table 1). The cumulative citation of all three articles is 42 (according to SCOPUS, August 2023). It is interesting to note that all three publications covered the contents of organic chemistry, and the studies were conducted in two countries, Greece and Serbia. Table 1 summarizes the basic descriptives about articles found in our analysis.

Table 1. The basic descriptives about selected articles

	Publication journal	Publication year	Research area	Country	Citations
Vachliotis and colleagues [13] - **A1**	Research in Science Education	2014	Organic chemistry	Greece	18
Vachliotis and colleagues [5] - **A2**	Thinking Skills and Creativity	2021	Organic chemistry	Greece	4
Hrin and colleagues [12] - **A3**	Thinking Skills and Creativity	2017	Organic chemistry	Serbia	20

This qualitative study used a content analysis approach to identify similarities and differences within selected articles. The common parts of the research within all three articles are the inclusion of the STARubric, the focus on high school students and organic chemistry contents. However, the articles marked as *A1*, *A2*, and *A3* (see Table 1) can be distinguished according to the following descriptors:

D1. Qualitative / quantitative exploration of suitability of new instruments and STARubric for systems thinking assessment.

D2. The validation of new instruments and rubric through validity and reliability analysis.

D3. The exploration of the relation between the students' systems thinking and other relevant constructs or factors (e.g. gender, or meaningful understanding);

D4. The examination of the impact of the SATL instructional strategy on the students' systems thinking development.

DISCUSSION

In order to compare the selected articles, firstly it should be said that all three articles satisfied descriptors *D1*, *D2*, and *D3*. Namely, the authors have designed new instruments, i.e. SAQs and their more specific sub-type – SSynQs that focus on synthesis reactions, in order to examine the effectiveness and suitability of instruments for systems thinking assessment (see descriptor *D1*). It must be highlighted that the great contribution of the study marked as *A1* (see Table 1) is the fact that SAQs were for the first time applied in an empirical study in order to examine high school students' systems thinking in the domain of organic chemistry. The constrained format of SAQs with a given, partially fulfilled diagrammatic form was used and the high school students were required to complete it by writing elements that were missing (e.g. names and formulas of missing organic compounds, types of organic chemistry reactions, reagents and the conditions of the reactions). In the next study of the same authors (marked as *A2* in the Table 1), the fill-in-the-blank SAQ items were also designed based on the results of the previous research [13] to capture high school students' systems thinking skills in organic chemistry domain (regarding the chemistry of alcohols and carboxylic acids). Even though in our study (marked as *A3* in Table 1), we also used constrained fill-in-the-blank format of SSynQs with given diagrammatic form, the main difference was in the fact that all concepts included in our diagrammatic form were directly included in the "closed cluster" (i.e. each concept was linked with at least two neighboring concepts, see Fig. 2). In the studies of Vachliotis and colleagues (marked as *A1* and *A2* in Table 1) the SAQs contained concepts that included multiple relationships, however, there where concepts that were related with only one additional concept, too. Therefore, our SSynQs contained fewer number of concepts integrated in "closed cluster" of SSynQs (i.e. from 5 to 9), in comparison to the SAQs used in *A1* and *A2* which included more than 10 concepts, while several of them were provide to the students. In all three studies, high school students' answers on SAQs / SSynQs were evaluated by using previously described STARubric, and the following was concluded:

- SAQs / SSynQs are useful instrument for assessing systems thinking skills in organic chemistry domain as, in order to be solved, they require skills such as making distinction between concepts, linking and organizing concepts, and taking multiple perspectives. The level of student's success in these processes determines the level of his/her level of systems thinking. Therefore, SAQs / SSynQs are appropriate tools for classifying students into different levels of systems thinking skills.

Additionally, the set of these instruments showed acceptable psychometric properties such as good validity and reliability (see descriptor *D2*). For example, the evidence of reliability in *A1* study was determined by calculating inter-rater reliability by using Cohen κ coefficients which were calculated to be sufficiently high (0.81 and 0.85). The reliability parameter in *A2* was determined by finding very strong positive correlation ($r = 0.95$) between systems thinking level scale and scoring method noted as "one point for each correctly written concept". Additionally, the reliability of internal consistency, by calculating the Cronbach's alpha coefficient, was performed in the study *A3* for all four levels of systems thinking. The Cronbach's alpha coefficient was found to be high in the range from 0.773 to 0.797. In the same study, *A3*, the concurrent validity was estimated when regression analysis was conducted between variables: students' performance scores on SSynQs and conventional questions. The significant values of Pearson's *r* coefficient were found between students' performance scores on conventional questions and lower levels of systems thinking (i.e. first and second levels).

The authors of the analyzed studies find in quite important to include additional construct or factor in order to correlate it with the systems thinking (see descriptor *D3*). More about that will be discussed in the continuation of this section. The associations between systems thinking construct and students' meaningful understanding represented significant part of the investigation in *A1* and latter *A2*. Namely, SAQs were originally designed with the intention to capture students' meaningful understanding in the chemistry. By analyzing students' answer on SAQs, the authors in *A1* found that systems thinking levels were strongly related with the students' deeper understanding of organic chemistry concepts, i.e. with their meaningful understanding. In addition, study within *A2* provided a continuing flow of the previous research *A1* about this issue. The main difference between *A1* and *A2* was in the research design, as now, within the *A2*, the authors implemented the pre-test/post-test nonequivalent control group design. The comparison between the experimental, *E* group (the implementation of SATL strategy in the teaching and learning process) and the control, *C* group (traditional classroom teaching) in *A2*, enabled the examination of the impact of the SATL instructional strategy on students' understanding in organic chemistry (fulfilled descriptor *D4*). An important influence of the SATL instructional strategy on students' meaningful understanding in organic chemistry was observed. However, the research design required only *E* group students to solve SAQs as validated instruments for assessing students' systems thinking skills. Then, the relationship between students' systems thinking skills and their understanding of chemistry concepts was explored only within *E* group students, and a strong positive correlation was found. The conclusion was that the level of systems thinking development is associated with the understanding of relative scientific concepts in the domain of chemistry. The SAQ test was not administered to the control group, because, according to the authors' opinion, these students were totally unfamiliar with the SATL strategy in chemistry.

The study marked as *A3* followed the experimental / control group research design, where *E* group students were trained in the SATL strategy similarly as in the *A2* (fulfilled descriptor *D4*). Before the research was conducted, the authors prepared both the learning sheets with fill-in-the-blank SSynQs, as well as final test with SSynQs and conventional (objective) questions (i.e. multiple-choice, open response, matching, and completion type questions). The C group students received short instruction about SATL strategy and SSynQs principles of solving before testing has started as they were not familiar with any of aspects of SATL strategy. Therefore, one of the differences between studies *A2* and *A3* was in the fact that *C* group students in A3 study solved both conventional and SSynQs on the final testing. Namely, the *E* and *C* groups were subjected to the exactly the same research instrument. The results showed that the students who were subjected to SATL approach and worked with [SSynQs] on classes developed all four levels of systems thinking in a more effective way that students who continued with traditional teaching and learning. Namely, the positive, high impact of SATL instructional strategy on students' systems thinking skills was highlighted, as students from the *E* group outperformed students from the *C* group in all four levels of systems thinking, and the *C* group students did not develop abilities of dynamic and cyclic relationships between elements of the organic chemistry systems and sub-systems (see descriptor *D4*).

In the same study *A3*, the issue of gender in regard to the construct of systems thinking was examined (fulfilled descriptor *D3*). No significant differences between male and female students were found in the *C* group. However, in the *E* group such difference was noted as *E* group female students outperformed male students in identification of dynamic and cyclic relations between concepts (III and IV levels of systems thinking). The conclusion about gender issue made in this study [12] was that application of SSynQs is more suitable for female students in order to develop higher order thinking skills such as systems thinking skills. It is interesting to note that in the next study of the same authors [15] one of the conclusions was that male students could benefit more from SATL instructional strategy if they receive longer lasting instruction with SSynQs.

SUMMARY AND FUTURE DIRECTIONS

This paper reported on our review of systems thinking construct in relation to the systemic approach to teaching and learning, SATL, chemistry. The SCOPUS database was used to find the empirical peer-reviewed articles that integrated both systems thinking and SATL approach in chemistry education. The qualitative content analysis applied to the selected studies indicated that all of them were conducted within high school organic chemistry domain and used scoring rubric developed on the theoretical and methodological bases of systems thinking framework called DSRP. The original and modified versions of scoring rubric (called STARubric for the purpose of this paper) was successfully used in three studies marked as *A1*, *A2*, and *A3* (see Table 1) in order to assess high school students' systems thinking skills through the defined levels. However, there are some challenges in implementing DSRP in developing process of STARubric. It seems like one aspect of DSRP model has been neglected. Namely, it is agreed that systems thinking refers to the application of four cognitive rules or skills to the given task or information. These are making distinctions, identifying systems, determining relationships, and making different perspectives, including awareness of our own thoughts which is also known as metacognition [30]. There are many theories how to develop metacognition, however, there is no study that examined the application of SALT instructional strategy in order to develop students' metacognition. This would provide the inclusion of additional variable to find valuable relations with students' systems thinking (noted here as descriptor *D3*).

Another interesting finding was in regard to the triangle between the students' gender, SATL instructional approach, and systems thinking construct. In the studies that used SATL instructional approach for the shorter period of the instructional time, e.g. within one or two teaching topic, female students scored higher observing the levels of systems thinking [12], or meaningful understanding [21]. However, when the students were exposed to the work with SSynQs for the longer period of class time, the male students benefited more from the SATL approach [15]. Perhaps there are sub-types of SAQs that are more suitable for the male students in order to develop higher order thinking skills. These could be systemic analysis questions, SAnQs, or systemic sequencing questions, SSQs. They should be examined together with the issue of students learning styles. Certainly, there are plenty of directions for future research in this approach that would be highly contributing.

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