1ST AFRICAN CONFERENCE ON RESEARCH IN CHEMISTRY EDUCATION [ACRICE-1]

MAIN THEME:  

Chemical Education for Human Development in Africa

ORGANIZED BY:  

FEDERATION OF AFRICAN SOCIETIES OF CHEMISTRY (FASC)  

AND  

ADDIS ABABA UNIVERSITY, ETHIOPIA

Date: From 5 to 7 December 2013  
Venue: Addis Ababa, Ethiopia

Papers will be presented under the following sub-themes (ST)

ST [A]: Best Practices in the teaching and learning chemistry  
ST [B]: Chemistry education for sustainable development in Africa  
ST [C]: ICT and Multimedia in teaching and learning chemistry  
ST [D]: PCK/TPACK in Chemistry  
ST [E]: Nano–chemistry Education  
ST [F]: New trends in student assessment  
ST [G]: Micro-Scale chemistry teaching  
ST [H]: Ethics in chemistry education  
ST [I]: Multiple uses of chemicals  
ST [J]: Lab safety and hazards  
ST [K]: TQM, TQC in chemistry education  
ST [L]: SATLC Applications  
ST [M]: New Trends in Teaching and Learning Pharmaceutical and Medicinal Chemistry

Preconference Workshops (WS) will be on

WS-1: Systemic Assessment as a New Tool for Assessing Students’ Achievements at Higher Learning Levels  
WS-2: ICT in Teaching and Learning Chemistry  
WS-3: Micro-and Semi micro Scale Chemistry  
WS-4: Lab safety and hazards

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EDITORIAL

CHEMICAL EDUCATION
FOR THE HUMAN DEVELOPMENT IN AFRICA

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Dear AJCE Communities,

My intention here under the title “Chemistry Education for Human Development in Africa” is not to present an article but to direct your attention and to welcome you to the First African Conference on Research in Chemistry Education (ACRICE-1) with the theme of the title of this editorial.

At the occasion of the celebration of the 50th Anniversary of the African Union, ACRICE-1 comes to bring together university staff members, chemistry educators and chemistry teachers from across the African continent and the world at large and provide a unique pan-African forum for the sharing ideas and new findings to solve education problems in African countries. Participants will examine a wide range of pedagogical best practices that address local and global issues in educating African students for total quality in the global age.

The ACRICE conference is intended as a platform for understanding and enriching education for preparation of African citizens who are able to deal with local and global challenges. To that end, educators and researchers at all levels are invited to share vital knowledge and strategies for teaching and learning in culturally responsive ways.

So you are most welcome to the first of its kind event in Africa that is scheduled for 5-7 December 2013 in Addis Ababa, Ethiopia. The conference will be preceded by workshops on selected topics of current interest in chemistry education. The organizers strongly believe that
such a forum will greatly benefit chemistry educators and teachers at all levels. We therefore appeal to international organizations, national private institutions and ministries of education, science and technology to support the participation of African chemists and chemistry educators in the event.

See you in December 2013 at ACRICE-1!
WEAVING TOGETHER CLIMATE SCIENCE AND CHEMISTRY EDUCATION IN AN AFRICAN CONTEXT

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ABSTRACT
Integrating meaningful contexts into chemistry education offers potential benefits for both students and instructors. Weaving together the teaching and learning of chemistry with the rich context of climate science provides opportunities for educators to increase student motivation, enhance classroom experiences and equip students to use fundamental understanding of science and problem-solving skills to begin to address some of our planet’s most important and complex challenges. Improved climate literacy is especially important to African students and teachers because of Africa’s vulnerability to climate change. This paper describes the development of a new set of interactive, web-based resources, Visualizing and Understanding the Science of Climate Change (www.explainingclimatechange.com), which explores various climate topics and illustrates ways in which connections between chemistry and climate change can be drawn out in chemistry courses at the secondary and post-secondary level. Dual goals are to improve chemistry conceptual understanding and to empower African students to understand and effectively respond to the climate challenges currently facing their continent. [AJCE, 3(2), June 2013]
INTRODUCTION

Teaching and Learning Chemistry in Meaningful Contexts

Meaningful contexts for the teaching and learning of chemistry can enrich the experience of students in their encounters with chemistry at the secondary and postsecondary level (1, 2). By integrating contexts that matter to students with the learning of chemistry concepts, chemistry educators may increase student motivation, facilitate better understanding of chemistry concepts, make teaching more satisfying for instructors, and equip students to apply their understanding to important real-world contexts - thus working at higher levels on learning taxonomies (3). However, teaching chemistry in this way, especially to cohorts of students majoring in science, is unfamiliar to many students and chemistry educators. Even experienced teachers in a teacher development course for teaching chemistry concepts in contexts experienced difficulty linking meaningful contexts with introductory chemistry content (4, 5). Thoughtful attention to providing the right resources to support learning and teaching is one of the necessary conditions for successful implementation of rich contexts in chemistry teaching, and is the focus of this paper.

As an example, consider a chemistry educator at the secondary or introductory post-secondary level in Addis Ababa who is covering a unit on phases, and is introducing the concept of vapor pressure of gases and its dependence on temperature. How can this educator present the topic so that it is not a set of isolated, irrelevant facts? How can students in this chemistry course be helped to see how important the tools of chemistry are to their lives?

To demonstrate the relevance of the chemistry content, the educator might show how the concept informs a significant challenge faced by the students. One such global challenge, with integral connections to chemistry, is climate change. The current and projected effects of climate
change upon the entire globe are well-documented; however, Africa faces some particularly vexing climate change challenges, many of which result from human activity elsewhere in the world. Chemistry education has an important role to play in equipping the next generation of scientists and citizens to address those challenges.

The Challenge of Climate Change for Africa

Some of the greatest impacts of planetary-scale changes in the earth’s climate systems will be felt far from the largest sources of greenhouse gases that contribute in such a substantial way to global climate change. African climate is highly diverse and variable, and the livelihood of many Africans heavily depends on the climate (6). Because of this, Africa is considered to be particularly vulnerable to climate change (6, 7). An especially important vulnerability results from the modeled impact of climate change on water availability, which is a major concern in sub-Saharan Africa (6). Due to climate change, by the 2050s, the population at risk of increased water stress is projected to be somewhere between 350 and 600 million Africans, although the regional impact of climate change on precipitation is highly variable (7, 8). In addition to the resulting shortages in drinking water, changes in rainfall patterns are expected to reduce agricultural productivity (9, 10). Because food shortages are already a reality for many African countries, the adverse effects of climate change on agriculture are a serious concern (11).

Africa is also the continent with the lowest life expectancy (12). Health issues are expected to intensify due to climate change because, according to models, climate change will lead to the increased frequency, intensity and duration of heat waves (13). These heat waves will have particularly severe effects on children, increasing their vulnerability to disease, and raising morbidity and mortality rates (14).
Finally, social conflict may be exacerbated by extreme precipitation conditions—conditions of either severe wetness or severe dryness (15, 16). Because climate change is projected to generate more extreme rainfall events in Africa, in which extended periods of dryness are interspersed with violent storms, climate change may contribute to higher frequency or severity of social conflict (15).

The Importance of Climate Literacy and Chemistry Education in Africa

Due to the particular vulnerability of African countries to climate change, increasing climate literacy among Africans is crucial to equip the next generation of Africans to understand the challenges and know how to respond to them effectively. Since climate science builds on fundamental knowledge of chemistry and other sciences, an important opportunity is presented in chemistry classrooms and laboratories to build connections between climate literacy and chemistry concepts.

What approaches to integrate the learning of chemistry concepts with climate literacy objectives could be taken by our Addis Ababa chemistry educator, who is teaching about phase changes of water? By drawing a deep connection between vapor pressure dependence on temperature and the effect of climate change on water resources in Africa, the educator can enable students to understand the concepts about physical properties and phase changes, while building literacy about the impact of climate change on students’ lives. This simple scenario illustrates the power of using climate change as a rich context for teaching and learning fundamental chemistry principles. With knowledge of both the fundamental science and the implications for changing climate, students can be encouraged to consider their responsibility to respond to climate change, and to make informed decisions that help address the issue.
THE RESOURCES – VISUALIZING AND UNDERSTANDING THE SCIENCE OF CLIMATE CHANGE (www.explainingclimatechange.com)

An Overview

We report the development and dissemination of an interactive, web-based educational resource, targeting students, educators, and the general public, designed to help bridge the gap between climate literacy and fundamental chemistry principles. The interactive, web-based resources, *Visualizing and Understanding the Science of Climate Change*, can be accessed at www.explainingclimatechange.com. Resources were created over a period of five years as an International Year of Chemistry legacy project by students and faculty at the King’s Centre for Visualization in Science, under the umbrella of an International Union of Pure & Applied Chemistry (IUPAC) project. Partners collaborating on the project, and providing review of the resources by both scientists and educators include the Royal Society of Chemistry (RSC – UK), the American Chemical Society (ACS – USA), the Federation of African Societies of Chemistry (FASC), and UNESCO.

*Visualizing and Understanding the Science of Climate Change* is organized into nine lessons, and addresses a variety of climate topics, with a strong emphasis on drawing connections to underlying chemistry concepts (Figure 1; Table 1). Simulations, videos and assessment items are included within each lesson, to help facilitate the user’s learning. Every lesson is also followed by “Test Your Knowledge” questions, which students may employ to reinforce their understanding or which educators may use to test the knowledge of their students. In addition, pop-up definitions and an extensive glossary allow users to acquire familiarity with the many terms that are fundamental to the science of climate change.
Figure 1. Opening screen of Visualizing and Understanding the Science of Climate Change (click on the image to link directly to the resource)
Table 1. Lessons and Key Ideas in *Visualizing and Understanding the Science of Climate Change*

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Design Principles of *Visualizing and Understanding the Science of Climate Change*

The pedagogical design of *Visualizing and Understanding the Science of Climate Change* is fundamental to its effectiveness in improving climate literacy and teaching underlying chemistry principles. Principles incorporated into the design include interactivity, guided inquiry and self-assessment (17). The resource is highly interactive, containing numerous simulations in which the user is able to adjust the conditions of a system and observe the results. Other work suggests that a high degree of interactivity can be effective in facilitating student learning (17). In explainingclimatechange.com, students are guided through an inquiry process, rather than told facts that need to be memorized (17). For this reason, when data is presented, the resource does...
not directly state the conclusions that can be made. Instead, directive questions are employed to encourage the user to interrogate the data and arrive at the appropriate conclusions independently. Finally, the resource integrates numerous formative and summative assessment items, which reinforce the information that has been presented and allow the users to ensure that they have understood the key concepts. These self-checks also help to maintain focused time on task, preventing the user from clicking rapidly through the resource.

**Key Topics in Visualizing and Understanding the Science of Climate Change**

**Climate Change and Water**

Various sections of the resources address the connection between climate change and the water cycle, which, as noted above, is of particular concern in the African context. In Lesson 6, *Greenhouse Gases: A Closer Look*, the user is able to visualize the effect of increased temperature on water evaporation through an interactive graph and animation (Figure 2). The warming trend associated with climate change results in increased concentrations of atmospheric water vapour through higher rates of evaporation. Because the user has learned that water vapour is a greenhouse gas, questions guide the user to consider how increased evaporation of water results in a positive feedback loop that compounds the effect of climate change. However, increased atmospheric moisture may also increase local cloud cover, which contributes to increasing earth’s albedo and is an example of a negative feedback loop. These opposing feedbacks are complex and can operate on both different geographical and time scales.
Figure 2. The temperature dependence of water vapor pressure displayed with an interactive graph and animation (click on the images to link directly to the learning tools)

The concept of water feedbacks is explored in greater detail in Lesson 7, *Climate Feedback Loops*. In addition to the feedback effects described above, increased global temperatures also lower earth’s albedo through the melting of polar snow and ice. Using the *Polar Ice Cap Measurement Learning Tool*, the user is able to measure the area of polar ice from different years and observe and quantify the decrease in polar ice over the past 3 decades (Fig 3).

Figure 3. Using an Interactive Tool to estimate the area of polar ice in the year 2010 (click on the image to link directly to the learning tool)
At first encounter, African students may not consider the shrinking of polar ice to be of great regional relevance, but the user learns in Lesson 4, *Climate: A Balancing Act*, that loss of polar ice lowers Earth’s albedo, which leads to greater absorption of solar radiation and amplified warming. Because of African vulnerability to climate change, any process that intensifies the effects of climate change holds importance for Africans, including the melting of polar snow and ice. Furthermore, substantial populations living in African coastal cities will be affected by even moderate sea level rise.

Lesson 5, *A Global Issue: The Impacts of Climate Change*, touches on the issues of water availability and soil moisture, discussing the effect of climate change on the frequency of extreme weather events such as heavy rainfall and drought. In this lesson, the user is encouraged to consider the societal and economic implications of increased instances of both heavy precipitation and drought. The user is also able to examine simple models for these predictions using the *Visualizing Global Climate Change Learning Tool*. With this tool, the user can observe the modeled evaporation differences in various cities around the globe, relative to an average reference value from 1960 – 1990, as projected by various Intergovernmental Panel on Climate Change (IPCC) Special Reports Emissions Scenarios (18). For example, the tool projects that by 2100, the city of Lagos may experience higher evaporation than the 30-year average for the reference period of almost 0.5 mm/day under the moderate A1B emissions scenario (Figure 4). With increased evaporation, soil moisture would be decreased, consistent with projections that climate change will likely lower agricultural productivity. These models were created from the IPCC Scenarios by using the Educational Global Climate Modeling or EdGCM software, which is an extensive suite of climate modeling tools developed at NASA’s Goddard Institute for Space Studies (19).
Figure 4. Change in evaporation (from the 30-year average reference value) by the year 2100, with the city of Lagos highlighted *(click on the image to link directly to the learning tool)*

**Evidence for Climate Change**

Students may have little experience in evaluating scientific claims, and in discriminating between scientific evidence for climate change and the claims made by a few contrarians, who publically dispute the conclusion that temperature increases since the Industrial Revolution have a human signature. Data does show that earth has experienced numerous and regular natural temperature fluctuations throughout our planetary history. Interrogating the evidence can help the user see and understand what we do know about the connection between human activity and the current surface air temperature rise.

In Lesson 2, *Is Climate Change Happening?*, the user is introduced to the study of ice cores, which climate scientists use to reconstruct the average temperatures of the earth hundreds of thousands of years ago. The *Isotope Ratio Mass Spectrometry (IRMS) Learning Tool* (Figure 5) describes how the isotopic ratios of oxygen or hydrogen in specific ice core layers are
analyzed using Isotope Ratio Mass Spectrometry to provide a proxy measurement of Earth’s temperature over time. The Ice Core Extraction and Analysis Learning Tool, also shown in Figure 5, describes how ice cores are extracted, preserved and analyzed.

Analysis of proxy temperature measurements from isotope ratios of water in ice cores clearly indicates that Earth’s temperature has fluctuated dramatically in the past. With the Climate Trends Learning Tool, the user is able to interact with and ask questions of the graphical presentation of historical temperature and greenhouse gas trends. As shown in Figure 6, the tool displays the Earth’s average temperature over the past 800,000 years, based on the ratio of heavy to light water in ice core samples.
Figure 6. Temperature records from the past 800,000 years determined from analysis of ice core data from Climate Trends Learning Tool (click on the image to link directly to the learning tool)

Figure 6 illustrates the fluctuations in mean global temperature over an 800 ka span and clearly shows many glacial and inter-glacial periods. The difference in average surface temperature for one of these episodes is on the order of magnitude of 8 – 10 °C, but much greater at the poles. The resource leads the user through a worked example in which earth’s average temperature is found to have fluctuated more than 10°C. Unsurprisingly, one may then ask why most climate scientists’ claim that the current increase in earth’s average temperature is caused by human activity and is not due to natural causes. One key element to making sense of the difference since the Industrial Revolution is analysis of the rate of change of temperature. The resource directs the user to find a rapidly rising temperature period over the past 800,000 years, and use a slope-measuring tool to find that, in the past, temperature changes occurred very slowly, often near a rate of about 0.001°C per year during the periods of steepest rise. Carrying out the same analysis for the past 100 years shows a rate of change an order of magnitude
greater, about 0.01°C per year. The difference in slopes suggests that something profoundly different is happening now and points to an anthropogenic signature in the recent data set.

The Climate Trends Learning Tool can also be used to show that the recent rapid increase in temperature is strongly correlated with increases in the atmospheric concentrations of several greenhouse gases, including carbon dioxide (Figure 7).

![Figure 7. Average temperature and atmospheric carbon dioxide concentration for the last 50 years, from Climate Trends Learning Tool (click on the image to link directly to the learning tool)](image)

By illustrating the correlation between the rapid increase in atmospheric carbon dioxide and the increase in temperature, this learning tool suggests that anthropogenic emissions of greenhouse gases are associated with climate change. As Lesson 2 illustrates the connection between atmospheric greenhouse gas concentrations and earth’s average temperature, the user may draw the conclusion that climate change is the result of human activity, rather than natural causes. The user is cautioned, however, to understand the difference between a strong correlation and a cause-effect relationship.
Linking Absorption of Electromagnetic Radiation by Molecules and Climate Change

Although the correlation between greenhouse gases and rising global temperatures is highly suggestive, one must understand the mechanism by which greenhouse gases warm the atmosphere in order to definitively grasp the connection between human activity and climate change. This concept is the focus of Lesson 3, *Heating it Up: The Chemistry of the Greenhouse Effect*. With the *Collisional Heating Learning Tool*, the user interacts with a visual model for how greenhouse gas molecules absorb infrared (IR) radiation at the wavenumbers required for vibrational excitation of molecules (Figure 8). The process of collisional de-excitation results in an increase in temperature, as vibrationally excited greenhouse gas molecules transfer energy to atmospheric gases such as $\text{N}_2(\text{g})$ and $\text{O}_2(\text{g})$, which are unable to directly absorb IR radiation. This provides an important context and motivation for understanding the kinetic-molecular theory.

![Figure 8. Absorption of IR radiation by a greenhouse gas molecule and collisional de-excitation in the Collisional Heating Learning Tool](image-url)
Lesson 3 also encourages the user to consider why greenhouse gases differ in their effect on atmospheric temperature by analyzing various factors that contribute to the radiative forcing of a gas. To facilitate the user’s analysis, the *Infrared Spectral Windows Learning Tool* displays the laboratory IR spectra of several greenhouse gases, allowing the user to observe the intensity and spectral regions of IR absorption for each of these gases. The blackbody emission curve of the earth can also be superimposed on top of the laboratory spectra, allowing the user to evaluate the significance of the IR spectral region in which a particular greenhouse gas absorbs strongly. As the user considers these factors that affect the importance of a greenhouse gas, the user obtains a solid understanding of the global warming potential of a gas, which is an important climate literacy concept. This is demonstrated in Figure 9, which shows that CFC-11, present in only ppt levels in earth’s atmosphere, and largely emitted from outside of the African continent, is nevertheless a contributor to climate change in Africa.

Figure 9. Laboratory infrared spectrum of CFC-11 with Earth’s emission curve superimposed in the *Spectral Windows Learning Tool* (click on the image to link directly to the learning tool)
Climate Change and the Future

While the underlying science of climate change is important for developing a basic understanding of the issue, the general public is most often concerned with the consequences and mitigation of the problem (20). Therefore, after the user has explored how humanity’s decisions have affected and will affect earth’s climate, the final Lesson 9, What Next? Responding to Climate Change, challenges students and teachers to consider how energy choices can either alleviate or exacerbate anthropogenic climate change. The Lesson makes use of two interactive learning tools, the Carbon Stabilization Wedges and the CO$_2$ Footprint Learning Tool.

The Carbon Stabilization Wedges Learning Tool allows the user to explore various strategies and currently existing technologies with the potential to stabilize annual carbon dioxide emissions at current levels, thereby preventing an additional 200 GT of carbon from entering the atmosphere over the next 50 years (Figure 10). Building on the Princeton Carbon Mitigation Initiative (21), the tool breaks down this challenge into one of removing eight smaller “wedges” of carbon from the projected emissions graph. Each of these wedges represents 25 GT of anthropogenic carbon that is prevented from entering the atmosphere over a 50 year period. With this framework, the tool enables the user to adjust conditions related to various mitigation strategies and observe the resulting effect on projected carbon emissions.
By exploring the tool, the user quickly learns a key concept: no single mitigation strategy will be sufficient to stabilize emissions, but a mosaic of solutions could be effective. Only if various strategies (within the categories of Efficiency, Decarbonization of Power, Decarbonization of Fuel, and Forests and Agricultural Soils) are implemented simultaneously can all of the “wedges” be removed from the projected emissions graph, stabilizing emissions at current levels. The tool also indicates the realism of a given set of conditions. Therefore, the user learns that, by scaling up several technologies or by employing several new practices, stabilization of carbon emissions is a feasible goal. Particularly relevant in the African context might be energy efficiency measures and the reductions in carbon emissions possible through reducing tillage of agricultural land.

The CO₂ Footprint Learning Tool is particularly relevant to understanding the potential effects of future human action in an African context. The tool allows users to build various carbon dioxide emission scenarios and observe the impact on atmospheric CO₂ levels. This is
done by numerically solving a complex, seven-compartment model that traces the exchange of CO₂ with planetary sinks and sources. A component is included that ties directly to population growth models and per capita CO₂ emissions defined over a regional level. In Lesson 9, the user is initially encouraged to utilize the tool to understand the relative magnitude of per capita carbon dioxide emissions for each continent, as well as each continent’s total carbon dioxide emissions. It becomes immediately evident that the average carbon dioxide emissions from an African person is much lower than the average emissions from an individual living on any another continent (Figure 11). Because earlier lessons have addressed the significance of carbon dioxide emissions, the CO₂ Footprint Learning Tool exposes the user to an unfortunate reality: although Africa is believed to be the most vulnerable continent to climate change, Africans have done relatively little to contribute to the severity of the problem (6, 7).

Figure 11. Per capita CO₂ emissions for Africa in the CO₂ Footprint Learning Tool, from Lesson 9, Key Idea 1 (click on the image to link directly to the learning tool)
Using this model, a user can adjust emission rates for a continent and observe the resultant atmospheric concentration of carbon dioxide until the year 2140. Growth scenarios on one continent can be applied to the world, to explore global effects of mitigation scenarios. For instance, the user could run a model in which each continent continues to emit at current levels and demonstrate that the atmospheric carbon dioxide concentration is expected to grow from the recent milestone of 400 ppm to above 600 ppm by the year 2100. Alternatively, one can simulate the effect of different scenarios for increased emissions. In Lesson 9, the user explores the consequence of growing emissions from Asia, which is a likely scenario considering Asia’s rapid industrialization and rising energy requirements. When a linear growth model of 10% is applied to Asia’s emissions, the concentration of atmospheric carbon dioxide is expected to drastically increase, reaching a value of about 900 ppm by 2100, even while the other continents maintain stable emissions (Figure 12).

Figure 12. Projected atmospheric carbon dioxide concentration, based on 10% linear growth of Asian emissions and stable emissions for all other continents (click on the image to link directly to the learning tool)
The tool can also strikingly demonstrate the positive effect of low emission rates. For instance, if the per capita emission rate of Africa is applied to the rest of the world, the model predicts that atmospheric carbon dioxide concentrations will only rise from the present day value of 400 to 460 ppm by 2100 (Figure 13). This value is much lower than the projected CO₂ levels based on current emission rates. Although this exercise highlights the need for action in other continents, it also points out the challenge of maintaining low African emissions, even as African nations seek greater industrialization and economic growth.

Figure 13. Projected atmospheric carbon dioxide concentrations with African per capita emission levels applied to all continents (click on the image to link directly to the learning tool)

Human emissions of carbon dioxide and the consequent increases in atmospheric carbon dioxide concentrations could provide rich contexts for various chemistry concepts and principles. Anthropogenic carbon dioxide emissions are primarily caused by combustion reactions, which are often used as core examples in chemistry to teach a variety of topics. The reactions which result in carbon dioxide emissions may also be used to introduce stoichiometric principles, and
ideas of atom economy and efficiency based on green and sustainable chemistry principles. Green chemistry is a topic which is gaining a strong foothold in chemistry curriculum at the post-secondary level. Carbon dioxide emissions are also fundamentally tied to the human requirement of energy, which could frame a discussion of thermochemistry. Chemistry educators may devise other creative ways to use human carbon dioxide emissions and the consequences for Earth’s future as a rich context for chemistry education.

VC3: USING OTHER CLIMATE SCIENCE RICH CONTEXTS TO INTRODUCE CHEMISTRY CONCEPTS

In a project that has built considerable synergy with the development of resources for explainingclimatechange.com, the King’s Centre for Visualization in Science is also a partner in a North American research group that is developing and piloting five topics taught in general chemistry through rich climate science contexts. The Visualizing the Chemistry of Climate Change (VC3, www.vc3chem.com) project has developed three climate topics to weave into the teaching of isotopes and atomic structure, gases, and acid-base chemistry and solution/precipitation equilibria. These three topics have been piloted in US and Canadian universities and colleges, and the research team is assessing whether gains in both chemistry conceptual understanding and climate literacy are achieved in first year university chemistry students through this approach. The concept question for introducing isotopes is a context related to temperature proxy measurements from ice core data; the concept question for gases is related to determining whether a gas is a greenhouse gas; and ocean acidification is used as the rich context to introduce acid-base chemistry and equilibria related to solubility and precipitation. A
fourth topic is presently under development, related to the coverage of thermochemistry in the first-year university chemistry curriculum.

CONCLUSIONS

Visualizing and Understanding the Science of Climate Change and the related Visualizing the Chemistry of Climate Change (VC3) project seek to implement best practices in the design and use of interactive web resources, as they weave together the dual goals of improving climate literacy and explaining foundational chemistry principles. African chemistry educators, such as the representative instructor introduced in the opening section of this paper, will find particularly strong connections to climate topics related to the water cycle, and can make use of resources to effectively teach concepts such as phase changes, vapor pressure, and the chemistry of water within a real world framework. With Visualizing and Understanding the Science of Climate Change, African chemistry educators can motivate student learning and enhance the classroom experience by relating fundamental chemistry principles to meaningful, real world challenges. In so doing, steps may be taken toward empowering students to understand and effectively respond to the challenges which climate change presents to the African continent.

REFERENCES


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STUDENTS’ ANXIETY TOWARDS THE LEARNING OF CHEMISTRY IN SOME ETHIOPIAN UNIVERSITIES

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ABSTRACT
Chemistry is a human endeavor that relies on basic human qualities like creativity, insights, reasoning, and skills. It depends on habits of the mind: skepticism, tolerance of ambiguity, openness to new ideas, intellectual honesty, and curiosity. The study was thus designed to find out students’ anxiety towards the learning of chemistry, identify the factors that cause the anxiety, examine the disposition of sex towards the learning of chemistry and suggest ways to increase their taste towards the learning of the subject. Data for the study were obtained by administering a questionnaire to 300 respondents. The data obtained were analyzed using frequency counts, percentages and stanine test. The finding of the study revealed that the students, whether male or female, urban or rural based, show great anxiety towards the learning of chemistry and that the anxiety is higher in female and rural based students than male and urban based students. The cause of students’ anxiety as revealed by the study includes; redundancy of the curriculum, low awareness of career opportunities, the teachers and their teaching methods and lack of teaching aids/laboratories. [AJCE, 3(2), June 2013]
INTRODUCTION

The role of science education in the lives of individuals and in the advancement of science and technology for the development of mankind and the society in general is very crucial. Scientific literacy, which is the gateway to achieve scientific and technological advancement and economic survival, is achievable through science education. The influence of science on a nation and its citizens could be seen from the production of basic human needs to social, political, educational, technological and economic advancement. The steps scientists take during scientific investigation (science processes) and scientific products draw the attention of the society to the fact that science makes life comfortable.

Chemistry is a very important science subject in senior secondary school curricula worldwide. It is a core subject for the medical science, textile technology, agricultural science, synthetic industry, printing technology, pharmacy, and chemical engineering. As important as the subject is and in spite of the efforts of both the federal and state governments to encourage chemistry education, students still shun the subject (1-2). It has been observed that most students fear chemistry and hence they see chemistry as difficult to understand, which may be as a result of the abstract nature of chemistry and the method (lecture method) being used by most of the chemistry teachers. Students’ anxiety for chemistry learning can also be attributed to students’ perception about the difficult nature of chemistry, involvement of multitude of facts, and its disconnection from reality (3). Students’ anxiety for chemistry learning leads to loss of interest in the sciences (4). In spite of the long existing fear and its effects on the subject, in Ethiopia researchers had done little or nothing on the basic psychological factors that could generate such anxiety.
PURPOSE, RESEARCH QUESTIONS AND METHODOLOGY OF THE STUDY

This paper aimed at finding out the causes of students’ anxiety towards the learning of chemistry. To achieve this stated goal, the paper will especially examine the basic factors that could cause students’ anxiety towards the learning of the subject. It will also assess the impact of sex and location of the students on their disposition and perception of the subject.

The paper is set to provide answers to the following research questions:
1. What are the causes of students’ anxiety towards the learning of chemistry in Addis-Abeba, Dire Dawa AND Adama Universities?
2. What is the impact of sex and background location of the students on their disposition and perception of the subject in universities?
3. What can be done to increase the students’ taste towards the learning of the subject?

The study employed the survey type of descriptive research. The population consisted of 2009/2010 second year chemistry students in three public universities (Dire Dawa, Adama and Addis Ababa). The multi stage sampling technique was used to select the subjects for the study. The students in the department were then separated in to their background location (rural and urban) and then according to sex type (boys & girls). In each university having ratio of one rural and one urban background were randomly selected. Thus a total of 360 subjects formed the sample. The only instrument used to generate data for the study was a structured questionnaire.

A pilot survey was first carried out and from its outcome, the main questionnaire was structured. The instrument was validated by three senior colleagues (one from science education, one from guidance and counseling and the third from test and measurement). Of the 360 copies of the questionnaire administered, 300 copies that were answered in full were analyzed using percentages and stanine test.
RESULTS AND DISCUSSIONS

This section provided answers to the research questions raised earlier in the study. The results are presented below.

A. Causes of Students’ Anxiety towards the Learning of Chemistry

From the survey, 40 factors that score students from learning chemistry were identified. These factors were then subjected to stanine test (where stanine 1-3 is low agreement 4-6 is medium agreement and 7-9 is high agreement). The students were also asked to rank 16 out of the 40 anxieties in order of severity. The highest ranked 16 among the anxieties using the stanine test are shown in Table 1.

Table 1. Students’ anxieties towards the learning of chemistry

<table>
<thead>
<tr>
<th>Causes of students anxieties</th>
<th>Number</th>
<th>%</th>
<th>Stanine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry syllabus is too wide</td>
<td>291</td>
<td>97</td>
<td>9</td>
</tr>
<tr>
<td>Chemistry demand too much of calculation</td>
<td>287</td>
<td>96</td>
<td>9</td>
</tr>
<tr>
<td>It is difficult to understand chemical equations and arithmetic</td>
<td>285</td>
<td>97</td>
<td>9</td>
</tr>
<tr>
<td>There are more failures in chemistry examination than passes</td>
<td>282</td>
<td>94</td>
<td>9</td>
</tr>
<tr>
<td>I don’t know where to work if I finish my course in chemistry</td>
<td>279</td>
<td>93</td>
<td>9</td>
</tr>
<tr>
<td>The major employment for chemistry is classroom teaching</td>
<td>270</td>
<td>90</td>
<td>9</td>
</tr>
<tr>
<td>I am scared by chemistry practical</td>
<td>262</td>
<td>87</td>
<td>8</td>
</tr>
<tr>
<td>I prefer Economics or Accounting to chemistry</td>
<td>252</td>
<td>84</td>
<td>8</td>
</tr>
<tr>
<td>Chemistry is too abstract due to the way the teacher teaches it</td>
<td>245</td>
<td>82</td>
<td>8</td>
</tr>
<tr>
<td>My chemistry teacher lack innovation, encouragement and resourcefulness</td>
<td>240</td>
<td>80</td>
<td>8</td>
</tr>
<tr>
<td>My chemistry teacher does not make use of teaching aids while teaching</td>
<td>238</td>
<td>79</td>
<td>8</td>
</tr>
<tr>
<td>Chemistry is too abstract because we’ve never seen most of the things being taught</td>
<td>231</td>
<td>77</td>
<td>8</td>
</tr>
<tr>
<td>The chemistry laboratory is ill equipped</td>
<td>225</td>
<td>75</td>
<td>7</td>
</tr>
<tr>
<td>Students are not exposed to practical until the final certificate examination approaches</td>
<td>216</td>
<td>72</td>
<td>7</td>
</tr>
<tr>
<td>No excursion, no fieldtrip so, no exposure</td>
<td>213</td>
<td>71</td>
<td>7</td>
</tr>
<tr>
<td>Chemistry teachers are too thorough in their assessment</td>
<td>210</td>
<td>70</td>
<td>7</td>
</tr>
</tbody>
</table>

From Table 1 above, the causes of student’ anxieties can be classified into four categories namely; the course content (syllabus), employment prospects, teacher’s interest and methodology and teaching aids and laboratory. All these boil down to curriculum planning and implementation. This finding corroborates the observation of the South African Ministry
Education (5) that the use of unqualified and under-qualified teachers has the tendency to influence teaching negatively with its implications on performance.

Ninety-seven percent (97%) of the students held the popular notion that the subject is too wide, demanding and rather cumbersome; about 96% of them feared chemistry because it demands too much of calculation while 95% were of the opinion that it is difficult to understand chemical equation and arithmetic. About 94% revealed that there are more failures in Chemistry examination than passes. Furthermore, about 87% of the students said they are scared by chemistry practical works.

The next fear of the students is based on employments prospect. Up to 93% indicated that they don’t know where to work and 90% believed that classroom teaching is the major employment opened to graduates of chemistry.

The third source of anxiety is centered on the teacher. Up to 82% say chemistry to be too abstract due to the method the teacher uses while teaching and about 80% accused the teacher of lack of interest, innovation, encouragement and resourcefulness. This is corroborated with the assertion of 79% of the students that their teachers don’t make use of teaching aids while teaching Chemistry. Another thing that kills the interest of the students as claimed by 70% of the students is the extra-ordinary thoroughness of the teachers in their assessments. These support the findings (6) that established a positive relationship between teacher’s quality and interest of students in science subjects.

The fourth source is lack of well-equipped chemistry laboratories, excursions and fieldtrips. No wonder 77% of the students complained that chemistry is too abstract because they have never seen most of the things being taught. This negates the major aim for chemistry teaching that the study of chemistry, among other things, will enable the student to know the link
between chemistry and industry, the environment and everyday life in terms of benefits and hazards.

Furthermore, 75% of the students attested to the poor condition of chemistry laboratories in their respective schools. This is responsible for the opinion of about 72% of them that students are not exposed to practical works until the final examination approaches. All these point to the fact that the students lack exposure as supported by the assertion of about 71% of them that there is no excursion, no fieldtrip and no exposure to real life related chemistry applications.

B. Impact of Gender on Students Disposition to the Learning of Chemistry

The study revealed that female students show more fear or anxiety towards the learning of chemistry than their male counterparts. Out of the 16 highest anxieties indicated, the male students showed higher anxiety over the females in just only five while the female’s recorded higher anxieties in eleven. The major problems of the males is centered (in descending order) on wide syllabus, ill-equipped laboratory, lack of exposure to practical works, lack of exposure to excursion and fieldtrips and strictness of the teachers.

The females are scared most by the broadness of the syllabus, too much of calculations, more failure than passes, job opportunity and quality and methodology of chemistry teachers. These fears partly justify the fewer number of students currently studying the subject in the universities studied. This finding clearly supports the established fact that gender differences exist in specific abilities of students (7-10) and that these differences are based on some in born characteristics (11).

C. Impact of School Location on Students’ Disposition to the Learning of Chemistry

A critical analysis of rural and urban students’ perspective towards the learning of chemistry shows that students in rural areas registered more fear in learning chemistry than their
counterparts in urban area. Among the highest 16 anxieties ranked, the rural students indicated greater anxiety in eleven while the urban students indicated in just five.

Students in the rural areas are scared by (in descending order) job opportunities, wide coverage of the syllabus, lack of exposure, teacher’s qualities and methodology and more failures than passes. On the other hand, urban students registered their anxieties (in descending order) in too many calculations, more failures and too wide syllabus.

This observation could be attributed to various factors some of which include:

- The quality and quantity of chemistry teachers in urban areas
- More exposure to things being taught and job opportunities in urban areas
- More opportunities of attending evening lessons extra-mural classes, etc than those in rural areas which give them the opportunity of covering and revising the syllabus before finally sitting for any examination, be it internal or external.

These findings are in line with Chambers and Andre (12) that differences between the genders in learning any physical science topic can probably be attributed to differences in prior experiences, interest and knowledge. There is no doubt that students in urban locations are more exposed than their counterparts in rural locations.

D. Suggestions to Reduce Students’ Anxieties

Lists of 20 suggestions or conditions were presented before the students to choose which of them when met will increase their interest to chemistry to any level. The highest 10 suggestions of the students are presented in Table 2.
Table 2. Suggestion to students’ anxieties

<table>
<thead>
<tr>
<th>Suggestions to Reduce Students’ Anxieties</th>
<th>Number</th>
<th>%</th>
<th>Stanine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of chemistry syllabus</td>
<td>285</td>
<td>95</td>
<td>9</td>
</tr>
<tr>
<td>Exposure of all career prospects to students</td>
<td>273</td>
<td>91</td>
<td>9</td>
</tr>
<tr>
<td>Provision of more qualified teachers</td>
<td>261</td>
<td>87</td>
<td>8</td>
</tr>
<tr>
<td>Organized many excursions and fieldtrips for more exposure</td>
<td>258</td>
<td>86</td>
<td>8</td>
</tr>
<tr>
<td>Encourage the use of instructional material and teaching aids</td>
<td>255</td>
<td>85</td>
<td>8</td>
</tr>
<tr>
<td>Provisions of standard and well-equipped chemistry laboratory</td>
<td>244</td>
<td>81</td>
<td>8</td>
</tr>
<tr>
<td>Exposure of students to practical chemistry right for university student</td>
<td>236</td>
<td>79</td>
<td>7</td>
</tr>
<tr>
<td>If my chemistry teacher can show interest in the subject, motivate and encourage me</td>
<td>230</td>
<td>77</td>
<td>7</td>
</tr>
<tr>
<td>If my chemistry teacher can improve on his teaching methods</td>
<td>226</td>
<td>75</td>
<td>7</td>
</tr>
<tr>
<td>Reduce exercises involving too much calculations</td>
<td>220</td>
<td>73</td>
<td>7</td>
</tr>
</tbody>
</table>

From Table 2, no wonder that students’ first request is the reduction of the syllabus given the fact that the major obstacle to most students who would have loved Chemistry is the overloaded syllabus. The curriculum developers are therefore called upon to further review and reduce the syllabus to a manageable size (without reducing the quality at the level) for both the teachers and the students.

About 91% of the students would be ready to study Chemistry to any level if they are exposed to all the career prospects in chemistry. There is thus the need for proper counseling to wipe off the erroneous notion the students already have that it is only in the classroom that a chemist could get a job. It is also necessary to make them understand the central role chemistry plays amongst the sciences and the various disciplines/courses in the tertiary institutions where chemistry is required as a prerequisite. It could also be beneficial if something like business chemistry and entrepreneurship in chemistry is introduced to students through appropriate means without overloading the already crowded curriculum.

In the third place we could see the students calling for more qualified teachers to teach the subject. It is pertinent to know that in some of the university studied just any teacher who graduated in any of the science courses is engaged in teaching chemistry. Besides, out of the
limited qualified graduate teachers, about 70% are in urban areas leaving just 30% to the rural areas. This clearly shows that the rural areas are at disadvantage in almost everything that could make the learning of chemistry real, interesting and meaningful.

Apart from quality, the quantity of chemistry teachers available in the schools is grossly inadequate and the few that are available are concentrated in the urban areas thus making those in the rural areas to be overloaded. This overloading effect will of course reduce their effectiveness, innovative ability, resourcefulness and encouraging power which the students also complained of. The government is therefore urged to intensify the training and employment of more qualified graduate teachers who should be evenly distributed among schools in rural and urban areas.

Another suggestion made by the students is the provision of standard and well-equipped chemistry laboratories, exposure of students to practical chemistry right from secondary school and organization of excursion and fieldtrips for more exposure. The findings of this study have revealed that not up to 20% of 80% of the universities have ever attempted fieldtrip or excursion either within or outside their environment for the past five years. Serious attention should be given to all these as they will further enhance the interest of the students in the subject.

The students also complained of poor teaching methods of their teachers and then suggested that they will love to study chemistry if the teachers can improve on their teaching methods. There is no gainsaying it that bad method of teaching will of course predetermine poor performance and kill students’ interest. The writers therefore enjoin all teachers teaching chemistry to be resourceful, motivating, enthusiastic and encouraging if actually we want to achieve the technological advancement we are yearning for in this nation.
SUMMARY AND RECOMMENDATIONS

The findings of this study revealed some of the basic causes of students’ anxiety towards the learning of chemistry such as wide coverage of the syllabus, low awareness of career opportunities in the subject, lack of exposure to excursion and fieldtrips, well equipped laboratory, as well as poor teaching methods. Although, all the students, whether male or female, urban-or rural based, show great anxiety towards the learning of the subject, the anxiety is higher in females and rural-based students them their male and urban-based counterparts.

Since the major obstacle to most students who would have loved chemistry is the redundancy of the syllabus, the curriculum developers are called upon to further apply the modular approach and reduce the redundancy to manageable size (without reducing the quality at that level) for both teachers and students. Teachers also need to be aware of the effects of anxiety on students’ achievement and motivation during their training so that they make an effort to lesson anxiety through:

- Developing teaching strategies that help highly anxious students
- Creating an environment in which students do not feel threatened and allow them to relax
- Using cooperative grouping to help students understand that others have the same problems as they do
- Teaching at a slow pace to help students better comprehend the material being taught
- Providing extra tuition sessions so that students are not left behind academically
- Paying serious attention to field trips and laboratory activities

With all these efforts it can be a positive force in reducing Chemistry anxiety. Chemistry teachers should show their students a sincere, caring attitude to help them overcome Chemistry anxiety.
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THE SYSTEMIC APPROACH TO TEACHING AND LEARNING HETEROCYCLIC CHEMISTRY [SATLHC]: OPERATIONAL STEPS FOR BUILDING TEACHING UNITS IN HETEROCYCLIC CHEMISTRY

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ABSTRACT
This paper focuses on the uses of systemic approach to teaching and learning in heterocyclic chemistry [SATLHC]. This work first presents the general strategy of converting linear traditional unites into systemic unites. Then it makes use of this general strategy in building unite of five-member heterocyclic compounds namely Pyrrole, Furan and Thiophene. The scenario of teaching the parts of this unite is also presented. This unite was presented as applicable model to convert linear unites to systemic unites in heterocyclic chemistry. [AJCE, 3(2), June 2013]
INTRODUCTION

After the wide spread use of systematization in various activities including, tourism, economy, security, education, etc, and after globalization became a reality that we live, SATL became a must and Chemical Education Reform (CER) has gained great importance internationally. SATL is a new way of teaching and learning, based on the idea that nowadays everything is related to everything globally. Students shouldn’t learn isolated facts (by heart), but they should be able to connect concepts and facts in an internally logical context.

Taagepera and Noori (1) tracked the development of student’s conceptual understanding of organic chemistry during a one-year sophomore course. They found that the student’s knowledge base increased as expected, but their cognitive organization of the knowledge was surprisingly weak. The authors concluded that instructors should spend more time making effective connections, helping students to construct a knowledge space based on general principles. Pungente, and Badger (2) stated that the primary goal of teaching introductory organic chemistry is to take students beyond the simple cognitive levels of knowledge and comprehension using synthesis and analysis – rather than rote memory.

Fahmy and Lagowski (3) suggested an educational process based on the application of “Systemics” named (SATL). The use of systemics can help students begin to understand interrelationships of concepts in a greater context, a point of view, once achieved, that ultimately should prove beneficial to the future citizens of a world that is becoming increasingly globalized. Moreover, if students learn the basis of the systemic process in the context of learning chemistry, we believe that they will doubly benefit by learning chemistry and learning to see all subjects in a greater context (4-6). SATL-in Heterocyclic Chemistry was experimented successfully on the third year major chemistry students at Ain Shams University (7-8).
What is the meaning of SATL?

By SATL it is meant an arrangement of concepts or issues through interacting systems in which all relationships between concepts and issues are made clear up front to the teacher and learner (5) as in figure 1 below.

![Figure 1: Concepts in SATL](image)

**Systemic teaching strategy: [STS]**

We started teaching any unit by Systemic diagram (SD0) that has determined the starting point of the unit, and we ended with a final systemic diagram (SDf) and between both we crossover several Systemics (5).

![Figure 2: Systemic teaching strategy](image)
The systemic diagrams involved in teaching are similar except that the number of known relationships (√) and the unknown (?) ones as indicated in the Fig.2. A list of SATLC materials were produced in Egypt, for instance, SATL General Chemistry for secondary schools, SATL Aliphatic, Aromatic, Green chemistry and Heterocyclic Chemistry for University Level. In this paper, systemic heterocyclic chemistry teaching materials will be illustrated.

USES OF SATL-IN BUILDING UNITES: [GENERAL BUILDING STRATEGY]

In SATL building strategy of unites, we convert the linearly based unites in chemistry to systemically-based unites according to the following general building strategy (9):

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

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

Third: Then content analysis of the linearly-based units into concepts, facts, laws, reaction types, mental and experimental skills.

Fourth: Draw a diagram illustrating linear relations among the concepts of the unit (figure 3).

---

Fig. (3): Linear relations between concepts of the unit
**Fifth:** We put the sign (√) on the already known relationships between concepts from previous studies. Then the remaining linear relations are unknown and signed by (?). So, the diagram in Fig-3 should be modified as shown in Fig. 4.

Fig (4): Linear relations between concepts after defining the known from the unknown

**Sixth:** The diagram in Fig.4 is modified to a systemic diagram SD0 as in Fig.5 by adding unknown relations between the concepts from 7 to 12. SD0 is known as the starting point of teaching the unit.

Fig (5): SD0 the starting point for teaching the unit

SD0 shows the systemic relations between concepts after defining the known from the unknown.
**Seventh:** In the scenario for teaching the unit, the student studies the relations 7, 8 and 9. So, he/she will be able to add them to SD0 diagram to give SD1 diagram as in Fig. 6.

![Fig. (6): SD1](image)

At this stage of teaching the unit we can ask the students to build systemics showing the relations between the concepts (X, Y, Z, and E) via systemic assessment.

**Eighth:** In the next stage of the scenario of teaching the unit, the student studies the relations 4, 5, 10, and 11 and then he/she will be able to add them to SD1 to obtain SD2- Fig. 7.

![Fig. (7): SD2](image)
**Ninth:** In the last stage of teaching the unit, the student studies the two relations, that is 6 and 12. Then he/she adds them to SD2 to obtain SD3-Fig.8 where we reached to the end of the systemic teaching of the unit.

![Systemic Diagram SD3](image)

**SD3** can be denoted as the terminal systemic SDf of the unit.

**Tenth:** 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 (Fig. 8). In going from SD0 through SDf we crossover several systemics with known and unknown relationships like SD1, SD2, etc. (9).

There are some difficulties in learning heterocyclic chemistry (HC) by traditional methods. The students find the following difficulties in learning HC:

- To remember the structural formulas of heterocycles and chemical properties related to these structures
USES OF SATL-IN BUILDING UNITES IN HETERO CYCLIC CHEMISTRY:

[APPLICATION OF SYSTEMIC BUILDING STRATEGY IN HC]

A course of heterocyclic chemistry using the SATL technique (8) was organized and taught to the 3rd year students at Ain Shams University. SATLHC means a survey study on the reactivity of both heterocycles and their substituents and the effect of heteroatom on their possible chemical relations.

C-Heteroatom: [(Z) = NH, O, S]

D-Substituents: [(G) = R, -CH₂ - X, -X, -CH₂ - OH - NH₂, -CHO, -COR, -COOH]
Scenario of Building Units on 5-Membered Heterocycles

We can apply the steps of general systemic building strategy (9) to build the unit of 5-membered ring as follows:

**First:** Draw a diagram that summarizes linear comparative reactivities of the 5-membered heterocycles as a model of heterocyclic compounds, and their possible chemical relations like in figure 9.

---

**Fig 9:** Linear comparative reactivities of the 5-membered heterocycles
The diagram in figure 9 represents the comparative reactivities of 5-membered heterocyclic rings, and gives the linear separated chemical relations among Pyrrole, Furan, and Thiophene, and their compounds.

**Second:** The diagram in figure 9 is modified to a systemic diagram SD1 (Fig.10) by adding relations between heterocyclic derivatives. SD1 summarizes the comparative reactivities of both heterocyclic nucleus and substituents.

The systemic diagram SD1 shows unknown chemical relations 1 through to 7 between heterocyclic compounds. These relations will be clarified later during the study of the unit [pyrrole, furan and thiophen].
Reactions of Pyrrole, Furan, Thiophene and Their Compounds

I-Pyrrole: (Prerequisites SD1):

Third: From Fig. 9 the student can deduce the reactions of pyrrole as in the following diagram (Fig. 11) by changing \([Z=NH]\).

![Diagram of Pyrrole Reactions](image)

The diagram (Fig. 11) represents the reactivity of pyrrole nucleus and gives the linear separated chemical relations between pyrrole and its compounds.

Fourth: The student can illustrate the chemical relations in Fig.11 systemically by modification of SD1 to SD2 (Fig.12) \((Z = NH)\).
Figure 12: SD2

Systemic diagram (SD2) shows

- **known chemical relations** between pyrrole and its compounds

- **Unknown chemical relations** between pyrrole compounds of 1 through 8 that should be clarified during the study of pyrrole compounds.

**Fifth:** After study of pyrrole compounds \([G = R, \text{CH}_2\text{OH}, \text{CHO}, \text{RCO}, \text{COOH}, \text{and NH}_2]\) the student can modify (SD 2 to SD 3) like in figure 13 by adding chemical relations 1 through 8.
In the systemic diagram (SD3) all the chemical relations between Pyrrole compounds are clarified as in 8 and 10. At this stage of teaching the unit we can stop and ask the students to answer Systemic Assessment Questions [SAQ, s] to assess students’ achievements on Pyrrole chemistry (11).

II-Furan: Prerequisite SD1

Sixth: From Fig. 9 the student can illustrate all the reactions of furan [Z=O] as in Fig. 14.
Figure 14: Reactivity of furan nucleus that gives the linear separated chemical relations between furan and its compounds

Seventh: From SD1 the student can illustrate the systemic chemical relations of furan in (Fig. 15) by modifying (SD1 to SD4) [Z=O]

Figure 15: SD4
The systemic diagram SD4 shows

(i) Known chemical relation between furan and its compounds

(ii) Unknown chemical relations between furan compounds as in 1 through 7

**Eighth:** After the next stage of the study of furan compounds \([G = R, X, \text{CH}_{2}OH, \text{CHO}, \text{RCO}, \text{COOH}]\) the student can modify (SD4 to SD5) like in figure 16 by additions chemical relations 1 through 7.

Figure 16: SD5

In the systemic diagram SD5 the chemical relations between furan compounds are clarified like 8 and 10. At this stage of teaching the unite we can stop and ask the students to answer Systemic Assessment Questions [SAQ.s] to assess students achievements on Furan chemistry (11).
III-Thiophene: (Prerequisite SD1)

Ninth: From Fig. 9 the student can summarize all the reactions of thiophene in the following diagram (Fig. 17). [Z=S]

Figure 17: The reactivity of thiophene nucleus that gives the linear separated chemical relations between thiophene and thiophene compounds

Tenth: The student can illustrate the chemical relations in (Fig. 18) systemically by modifying (SD1 to SD6) [Z = S].

Figure 18: SD6
The above systemic diagram (SD 6) shows

(i) The known chemical relations between thiophene and its compounds

(ii) The unknown chemical relations between thiophene compounds 1 through 6.

Eleventh: After the next stage of the study of Thiophene compounds \([G = R, X, \text{CH}_2\text{OH}, \text{CHO}, \text{RCO}, \text{COOH} \]) the student can modify (SD6 to SD7) as in figure 19 by addition of chemical relations 1 through 6.

![SD 7](image)

Figure 19: SD7

In the (SD7) all chemical relations between thiophen compounds were clarified as 8 and 10. At this stage of teaching the unit we can stop and ask the Students to answer Systemic Assessment Questions \([\text{SAQ,s}]\) to assess students’ achievements on Thiophene chemistry (11). At this stage we reach to the end of the unit.
CONCLUSIONS

After the experimentation of SATLHC in Egypt we reached to the following conclusions (7-8):

♦ SATLHC improved the students’ ability to view HC from a more global perspective.
♦ SATLHC increases students’ ability to learn subject matter in a greater context.
♦ SATLHC helps the students to develop their own mental framework at higher-level cognitive processes (application, analysis, and synthesis).

REFERENCES

EFFECTS OF TECHNOLOGY DRIVEN PEDAGOGY APPLICATIONS ON THE COMPREHENSION OF COMPLEX AND ABSTRACT CONCEPTS OF CHEMICAL EQUILIBRIUM

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ABSTRACT

Chemistry students often regarded abstract and complex Chemistry concepts as difficult to learn (1; 2) and this prevents many of them from continuing studies in pure chemistry courses. This study investigated how students develop their comprehension of complex topics of chemistry with the aid of Technology Driven Pedagogy (TDP) by using animation, simulation and video integrated with student-centered learning in visualizing complex and abstract concepts of chemistry. TDP technique in the chemistry classroom was used to promote effective learning. A chemist can view a chemical reaction at the macroscopic level, what the reaction will look like to the student’s eye, and at the particulate level, what changes are taking place among the particles. TDP is used to create mental images and displays on the macroscopic level. It also enables students to present information in a more dynamic, compelling and interactive way, engaging the environment prepared for learning by doing. To apply TDP in supporting student-centered learning activities, one week training on how to operate the computer with the experimental software was carried out on the experimental students of this study. This was followed by four weeks teaching and learning of chemical equilibrium topics for first-year undergraduate students with art technology flash and micro media player for 15 male and 15 female students who were conveniently grouped into control and experimental groups. A particular focus group of this investigation was used to determine to what extent the use of TDP can influence learning in Chemistry. This study employed sequential embedded mixed case study design. Pre and Post tests were administrated to the target groups. The quality of the learning strategy was evaluated by administrating open and closed ended questions containing schedule, focused group discussion, and observations. The results obtained from the tests, participants’ responses to the questionnaire schedule, focused group discussion and observation showed that TDP greatly improves the comprehension ability and performance of students in the subject. Therefore, TDP technique is a promising tool for simplifying and clarifying complex and abstract concepts of Chemistry and hence it is conclusively recommended by the researchers for a wider use. [AJCE, 3(2), June 2013]
INTRODUCTION

Applications of chemistry are ubiquitous, growing all over the world. It can be used in various aspects of societal needs. However, the widespread applications of Chemistry do not translate to the survival of the discipline in the school system with the number of chemists on a steady decline. It is becoming clear that Departments of Chemistry in many institutions are getting absorbed into other natural science fields.

Learning Chemistry at higher education level is complicated and difficult for students because it contains indistinguishable and intangible particulate concepts as it pertains to visualizing the atom, molecule, ions, and the interaction of these particles (3; 4; 5; 6; 7). Many researchers have done several researches to alleviate this problem but it is still exists (8). Learning is about how we perceive and understand the world, involve mastering complex principles, understanding proofs, remembering factual information, acquiring knowledge, skills and developing intended behavior suitable to specific situations; it is about change (8).

Excellence in learning involves achieving and maximizing effective teaching which encourages deep and high quality student learning, and active engagement with subject content (7). This helps them to respectfully see the world in a different way and establishing the kind of climate that will optimize appropriate interactions among students (9; 8; 10).

Therefore, chemistry students are expected to understand the scientific ideas at particulate level of matter in the manner that can be used to explain the properties of matter and different types of changes that take place in a vast array of chemical phenomena. The particulate nature of matter is fundamental to almost every topic of chemistry. This is the basis of explanations of atomic structure, bonding, molecules, chemical reactions, chemical equilibrium and chemical
kinetics. Chemical change involves the rearrangement of the constituent particles that make up the reactants, to give new configurations and characteristics of the products.

On the other hand, constructivism says that learning occurs by fitting new understanding and knowledge into and with, extending and supplanting old understanding and knowledge (11). Students are active rather than passive if they are exposed to increased amounts of information; their ability to solve problems, retain and transfer knowledge becomes very successful. But this is impossible without well prepared appropriate learning environment (12). Students of Chemistry are always thought what changes in a chemical reaction, i.e. the identities of the reactants and products involved. However, this simple view does not provide them with a comprehensive understanding of a universal phenomenon that is central to life, its maintenance, and continuation (13).

Teachers are expected to consider how to bring this changes or transformation to the pre-existing knowledge of their learners. Chemistry learning largely depends on students’ ability to understand the microscopic descriptions: how substances are formed and what are the functions of the substances. These microscopic worlds are usually not related to the students’ everyday experiences. Therefore, external representations are the only way, that can overcome these barriers (14), enable students to visualize and understand chemical reactions from a particulate point of view, to see why and how the change takes place. Such visualization would include not only the nature of the substances involved but also other aspects of the mechanism by which the reaction takes place. For example, the extent of the reaction, the rate at which it takes place and the factors that influences these aspects (13). The systematic use of carefully designed external representations such as technology driven pedagogy can make the microscopic world be familiar enough for students to be able to imagine and discuss the behavior of particles (15).
The Nature and Importance of Technology Driven Pedagogy?

For the purpose of this paper, we have used Technology Driven Pedagogy (TDP) as learning of abstract and complex content chemical equilibrium by means of visualizing software involving animation, simulation and video integrated with student-centered learning. Animation and simulation are systems that emulate the actual idea about the system being animated and simulated and its chemical phenomena are defined as artificial material object created or adapted for this intention. Whereas Video is the system of recording, reproducing, or broadcasting moving visual images on or from videotape, film or other recording on videotape (16). Students are to use computer animation, simulation or video according to their requirements to have clearer vision of complex and abstract chemical equilibrium concepts during their studies and interact with their group members to internalize the concepts.

The uses of animation and simulation techniques are strong on visualizing intangibles events, materials and facts to education and such are comparatively recent formats and standards that the teacher and students need to utilize to achieve a rapid development (17). Animation and simulation are powerful techniques that can enhance teaching about some aspects of the real world by imitating or replicating it. Learners are not only motivated and interested with these techniques but learn by interacting with them in a manner similar to the way they react in a real situation (16; 17).

The combined effects Animation, simulation and video integrating with appropriate student- centered learning or Technology Driven Pedagogy (TDP) have diverse advantages over other instructional modes of teaching. Students often participate more interestingly, intrinsically motivated with the use of TDP. It is very flexible in that both students and instructor have high degree of control and get closer to real world experience (18; 19).
TDP allows students to experience phenomena which could be dangerous, expensive, intangible, and even impossible to observe in the real world situation (20; 21; 22). Mental model exists in a learner’s mind, conceptual models are devices presented by teachers or instructional materials. Computer diagrams, animations, and video presentations have all been suggested as means of providing conceptual models that help develop learners’ mental models.

For the reason that TDP makes clear and simple the real-world phenomena, it facilitates learning by omitting what would otherwise be distracting elements in a real-world situation (18; 21). Finally, TDP can accommodate a wide range of instructional strategies, including micro worlds, scientific discovery learning, virtual reality, laboratory simulations, role playing, case-based scenarios, and simulation gaming (20; 15).

The purpose of this study was to determine how Technology Driven Pedagogy supports students’ comprehension of a complex and abstract concepts in university chemistry learning, such as the atom, molecule, ions, and the interaction of these particles in chemical. Thus, the objectives of this study were to:

- determine the effect and advantages of the use of TDP environment over student-centered technique learning on students’ comprehension of abstract and complex topics,
- identify which learning concepts of chemical equilibrium require TDP environments,
- discuss the implication of Technology Driven Pedagogy as a tool for teaching and learning.

Animation, simulation and video are concerned with External Representation, the systematic and focused display of information in the form of pictures and diagrams. There are several ways in which animation, simulation and video technology are expected to assist
learning. Animation, simulation and video are building a computer-generated” virtual” world. These features provide support for visualizing (22).

TDP not only provides rich learning patterns and teaching contents, but also helps to improve learners’ ability by clarifying complexity and exploring new concepts. These technologies are now maturing, and they enable even more complex and authentic interactions not only with regard to physical and cognitive fidelity but also the ability to integrate learning and training experiences into the real world to make learning more fun, interactive, effective, relevant and powerful (18). Significantly they are more successful at solving problems that required visualization. They promote current educational thinking that students are better able to master, retain, and generalize new knowledge when they are actively involved in constructing that knowledge in a hand on learning environment (15), allow students to explore, manipulate computer-generated, three-dimensional multimedia environments in real time. The TDP environment is suitable for illustrating indistinguishable concepts that involve spatial relationships, since the virtual world objects can be manipulated in a three dimensional space and viewed from multiple perspectives. It is a potentially powerful learning technology, which offers teachers a means to concretize particulate concepts for students and provide them with opportunities to learn by doing what they might otherwise encounter only in a textbook (16).

Designers and evaluators of animation, simulation and video systems express some ideas concerning how animation, simulation and video can facilitate learning. However, we should pay attention about information the animation, simulation and video best feet feature for enhancing understanding or how to customize those affordances for different learning environments. The design and development of effective educational chemistry software requires an expert approach.
It should be pedagogically appropriate technology and software development enables to acquire true knowledge based on the needs and difficulties of students’ chemistry learning (23, 24).

**RESEARCH METHODOLOGY**

The researchers used the sequential embedded mixed case study design to investigate the TDP approach compared to student centered approach because they believed that such a mixed method enhances the production of richer information that helps in thinking out of the box and provides comprehensive and full information.

In this research, data were collected mainly by adopting quasi-experiment and observations, while the data obtained by schedules and focused group discussions were used to support the information obtained by the quasi experiment and observations. In order to successfully conduct this study, a software, computer operation and focused group discussion training were given to students in the experimental group; a training process that lasted for one week. The training was set up to cover the various technological and pedagogical issues involved in the study. The first session aimed at familiarizing the students with the technology software and its use in the development of educational context, while the second dealt with the operation and the application of the technology in the classroom.

**Population and Sample of the Study**

The population for the study was all the 70 first year Chemistry students and 14 Chemistry lecturers of Debre Berhan University. First year Chemistry students were selected because most times they are more troubled and faced with the problem of poor concepts understanding in Chemistry.
First year students are busy with their courses; therefore, to get important data from willing participants a convenient (nonequivalent) sampling technique was employed to pick a sample size of 30 first year chemistry students and 5 lecturers.

**Data Gathering Instruments, Their Validity and Reliability**

The instruments of the study included observation check list, two types of schedules, containing open and closed ended semi structured questions and open-ended, focused group discussion prepared and administered by the researchers to the respondents. They were meant to examine the awareness, perception of students and lecturers, the students’ interaction and comprehension ability in Chemistry with special interest in Chemical Equilibrium.

Before distributing the tests, the instruments of the study were validated and discussed with the advisors and experts (22). The content validity index of the schedule for both lecturer and students similarly was 0.79 whereas the content validity index of the test was 0.81.

Reliability tests of the instruments were determined with Cronbach Alpha using the data collected from the Debre Berhan University lecturers and students who were not part of the main study with 0.86 and 0.88 reliability values respectively. The instruments were therefore used as such.

**Method of Data Analysis**

The researchers used t-test and the ANCOVA tools to compare the performance of the control and treatment groups of 1st year students using SPSS-20 statistical software (23) to analyze the quantitative data generated. On the other hand, the qualitative data obtained from open ended questionnaires, focused group discussions and observation were analyzed using
thematic and content analysis techniques. It involved categorizing the responses and classifying the ideas generated with appropriate data analysis done.

RESULTS AND DISCUSSION

Among the sample 27 (90%) of the first year Chemistry students and 5 (100%) lecturers who responded to the schedule and participated in the focused group discussion considered Chemistry as a difficult subject and not interesting because of its abstract, indistinct, and complex nature. Most of the time students face difficulties when they are exposed to such complex concepts. Moreover, both the students and the lecturers believed that student-centered and traditional way of teaching was not appropriate for all lessons of chemistry. But if students learn these concepts with TDP environment, it enables them to see those invisible, complicated processes and activities because the learning environment made the concepts clearer in meaning, sustaining effort and academic motivation.

TDP increasingly plays important roles both in learning and teaching. The fundamental principle of using TDP for learning was to create trust and clarity to all students of chemistry. This is because it is not wise to deliver as usual for students who have difficulty of learning complex and abstract concepts to learn more (1).

Individual students working with TDP had better class activities and skills than those who worked in a group without it. This shows clearly that there are times when individual work is necessary and when students should work alone under a quiet condition. Calm and quiet classrooms can lead to the production of very good work and can lead to effective learning. On the other hand, there is also a need for sharing and working together. Students who work in groups have better comprehension and communication ability, and they had deep and clear
concept understanding than individual students. Most of responses to the study schedules and the observations made suggest that TDP as an alternative way of learning is needed in domains where the interpretation of complex and/or abstract information is more demanding, as it happens in particulate level of clarification (Fig. 1).

![Figure 1: (a) When solid LiF is added to water, initially there are no ions in solution. (b) At equilibrium, cations and anions are present.](image1)

The reason for the above interesting observation is clear: it is easier to obtain understanding from a three-dimensional model than from the simple reading or hearing of lecture. The *Chemical Equilibrium experiment* aims at the conception of an educational environment, joining particulate illustration with three dimensional Technology Driven Pedagogy representations.

![Figure 2: A view of sodium chloride solution’s solubility equilibrium in water.](image2)
At equilibrium, ions dissolve from the crystal surface at the same rate as they are captured, so the concentration of ions in the solution remains constant. Visualization is thus, in the first instance, concerned with the formation of an internal representation from an external representation (see figure 2) such that the nature and temporal/spatial relationships between the entities of which it is composed are retained. An internal representation must be capable of mental use in the making of predictions about the behavior of a phenomenon under specific conditions (17).

The Statistical Analysis

Table 1: The pre and post test performance of students

<table>
<thead>
<tr>
<th>No</th>
<th>Control group</th>
<th></th>
<th></th>
<th>Experimental group</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre test</td>
<td>Post test</td>
<td>Gain</td>
<td>Pre test</td>
<td>Post test</td>
<td>Gain</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>12</td>
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<td>4</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>12</td>
<td>5</td>
<td>7</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>9</td>
<td>4</td>
<td>8</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>10</td>
<td>4</td>
<td>9</td>
<td>6</td>
<td>14</td>
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<td>9</td>
<td>4</td>
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<td>5</td>
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<td>11</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>12</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>12</td>
<td>7</td>
<td>15</td>
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<td>5</td>
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<td>4</td>
<td>13</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>14</td>
<td>5</td>
<td>14</td>
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<td>5</td>
<td>15</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>78</td>
<td>133</td>
<td>57</td>
<td>Total</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>5.20</td>
<td>8.85</td>
<td>3.73</td>
<td>Mean</td>
<td>5.07</td>
</tr>
<tr>
<td></td>
<td>Std</td>
<td>0.775</td>
<td>1.407</td>
<td>1.033</td>
<td>Std</td>
<td>.884</td>
</tr>
<tr>
<td></td>
<td>Gain</td>
<td>1.407</td>
<td>1.303</td>
<td>1.407</td>
<td>Gain</td>
<td>1.407</td>
</tr>
</tbody>
</table>
Table 2: Independent sample t-test result of pre test performance

<table>
<thead>
<tr>
<th>Test</th>
<th>F</th>
<th>P</th>
<th>t</th>
<th>P (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre test</td>
<td>.123</td>
<td>.729</td>
<td>.439</td>
<td>.664</td>
</tr>
</tbody>
</table>

This study assumed that there was no statistical difference (p < 0.05) between the mean chemical equilibrium performance in both the control (those who were taught through student centered technique of teaching) and experimental (those who were taught through student centered integrated with animation, simulation and video environment) group during the pretest. Chemical Equilibrium performance pre-test analysis, for control and experimental group given in Table 2, illustrates that no significant differences was found between the two groups, p value 0.646 is greater than 0.05. The pre-test mean scores and their corresponding standard deviation for both control and experimental groups given in Table 1, 5.20 (.775) and 5.07 (0.884), respectively also confirms their similarity. Besides, the Levene’s independent t-test for Equality of covariance’s for distribution of students both in the treatment and control group (p > 0.05) at t-value 0.439 and two tailed p-value 0.664 in Table 2, also supported the initial assumption that there was no significant difference between the two groups at the pre-test (p > 0.05) at \( \alpha = 95\% \)

Table 3: Paired Samples Correlations of pre test post test for each group

<table>
<thead>
<tr>
<th>Pair</th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>15</td>
<td>-.071</td>
<td>.803</td>
</tr>
<tr>
<td>Pair 2</td>
<td>15</td>
<td>.747</td>
<td>.001</td>
</tr>
<tr>
<td>Pair 3</td>
<td>15</td>
<td>-.049</td>
<td>.862</td>
</tr>
</tbody>
</table>
Table 4: Paired Samples t-test of pre-post test for each group and post-post test comparison

<table>
<thead>
<tr>
<th>Pair</th>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair1</td>
<td>Post-test-C – Post-test-E</td>
<td>-5.067</td>
<td>2.154</td>
<td>-9.112</td>
<td>14</td>
<td>.000</td>
</tr>
<tr>
<td>Pair2</td>
<td>Pre-test-C – Post-test-C</td>
<td>-3.667</td>
<td>.976</td>
<td>-14.552</td>
<td>14</td>
<td>.000</td>
</tr>
<tr>
<td>Pair3</td>
<td>Pre-test-E – Post-test-E</td>
<td>-8.867</td>
<td>1.807</td>
<td>-19.000</td>
<td>14</td>
<td>.000</td>
</tr>
</tbody>
</table>

According to the assumption that there is a significant difference (p<0.05) between the mean pre-test and post test score on Chemical Equilibrium performance, in both the control and experimental group, as shown in Table 3, there were no correlation between the post and pre test performance of two groups though there was a significant correlation between pre and post test performance of the control group which illustrates that there were no enhanced change in conceptual understanding in the control group, whereas there were higher levels of understanding of chemical equilibrium concepts in experimental group. The mean scores difference and corresponding standard deviation 5.067(0.2.154) at t-value -9.112 p-value is 0.000 for post tests, and -3.667(0.976) at t-value -14.552 the p- value is 0.000 and-8.867(.467) p-value 0.000 for control and experimental group, respectively also suggest that there was significant improvement in students performance in both groups though the improvement is greater in the experimental group.

Table 5: Paired Samples Test of the performance gain of control and experimental group

<table>
<thead>
<tr>
<th>Pair</th>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error of Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair1</td>
<td>Gain of control group - Gain of experimental group</td>
<td>-5.133</td>
<td>1.356</td>
<td>.3500</td>
<td>-5.884</td>
<td>-5.884</td>
<td>-4.383</td>
<td>-14.66</td>
</tr>
</tbody>
</table>
Comparing the gain scores of control and experimental group students, there was a significant difference between them (P < 0.05) as is shown in the Table 5 above. The table illustrates that experimental groups have better understanding of complex and abstract concepts of chemical equilibrium having been taught with the TDP and thus have better performance.

Prior to running the ANCOVA, the assumption that both experimental group and control group were not related was initially tested with homogeneity test. The ANCOVA test for homogeneity in Table 6, below shows the results for homogeneity slopes, the interaction between pre-test and teaching method was not significantly related (p-value 0.664 >0.05) and the results allowed the use of ANCOVA.

Table 6: Homogeneity slope test between pre test and method of instruction

<table>
<thead>
<tr>
<th>Post test</th>
<th>Mean Square</th>
<th>f</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of instruction pre test</td>
<td>.133</td>
<td>.193</td>
<td>.664</td>
</tr>
</tbody>
</table>

Table 7: ANCOVA test for post-test (N=30)

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>f</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>208.084(a)</td>
<td>3</td>
<td>69.361</td>
<td>39.973</td>
<td>.000</td>
<td>.822</td>
</tr>
<tr>
<td>Intercept</td>
<td>45.899</td>
<td>1</td>
<td>45.899</td>
<td>26.452</td>
<td>.000</td>
<td>.504</td>
</tr>
<tr>
<td>Teaching_style</td>
<td>27.658</td>
<td>1</td>
<td>27.658</td>
<td>15.939</td>
<td>.000</td>
<td>.380</td>
</tr>
<tr>
<td>*Teaching_style * Pre_test</td>
<td>9.885</td>
<td>1</td>
<td>9.885</td>
<td>5.697</td>
<td>.025</td>
<td>.180</td>
</tr>
<tr>
<td>Pre_test</td>
<td>7.683</td>
<td>1</td>
<td>7.683</td>
<td>4.428</td>
<td>.045</td>
<td>.146</td>
</tr>
<tr>
<td>Error</td>
<td>45.116</td>
<td>26</td>
<td>1.735</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4152.000</td>
<td>30</td>
<td></td>
<td></td>
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<tr>
<td>Corrected Total</td>
<td>253.200</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R Squared = .822 (Adjusted R Squared = .801)
Table 8: Estimated marginal means from ANCOVA (N=30)

<table>
<thead>
<tr>
<th>The teaching style</th>
<th>Mean</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>student centered</td>
<td>8.776 a</td>
<td>.341</td>
</tr>
<tr>
<td>virtual reality integrated with student centered</td>
<td>13.928 a</td>
<td>.341</td>
</tr>
</tbody>
</table>

Covariates appearing in the model are evaluated at the following values: The pre test = 5.13.

Table 9: The Univariate Tests of ANCOVA (N =30)

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>f</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast Error</td>
<td>197.644</td>
<td>1</td>
<td>197.644</td>
<td>113.902</td>
<td>.000</td>
<td>.814</td>
</tr>
<tr>
<td>Error</td>
<td>45.116</td>
<td>26</td>
<td>1.735</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

f - tests for the effect of the teaching style. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Investigating whether there is evidence for greater improvement in the experimental group than the control group on the mean post test score of Chemical Equilibrium performance, after the pre-test, it was evident that teaching the abstract and complex topics of Chemical Equilibrium with Technology Driven Pedagogy environment shows a significant improvement gains over the control group as shown in Tables 1 and 7. The effect size index rating (i.e. 0 = no effect up to 1(greater effect)) the eta-squared value in Table 9, and estimate marginal means in Table 8, also substantiated that the teaching method (\(\eta^2 =0.814\)) had greater effect on a post test performance based on Cohen et-squared value (0.01 very small, 0.06 medium, and 0.14 and above is greater (23).

This study results have shown that Technology Driven Pedagogy provides rich forms of learning and teaching processes. Almost 90% of Schedule responding and focused group participants in the study said that a lecturer who uses Technology Driven Pedagogy environment at Debre Berhan University can encourage intellectual inquisitiveness that can help students engage
actively and open new channels for success and provides opportunities for students to share their ideas (24).

When asked to compare this study`s approach with normal student-centered approach, 24(80%) of the students stated that student-centered supported with animation, simulation and video made the greatest contribution in terms of improving educational clarity, quality and students’ performance. Moreover, from the results of schedules, observation, focused group discussion and experimental results, Technology Driven Pedagogy learning environment encourages individually paced learning and mutual interaction of students and it enables to make clear learning and to improve academic performance of students. Thus, the combined effects of technologies such as animation simulation and video learning environment improve the attention level, activities and conceptual understanding of students. On the other hand, implementing this type of teaching and learning technique described in this paper:

- makes the learning process of complex chemistry topics clearer and simpler.
- improves the comprehension level of students
- enhances student’s ability to acquire concepts within a short period of time.
- helps students to attend their lessons with greater interest.

Collectively, such improvement in learning style may lead to profound changes in the way concepts are taught. “Learning will become more outcome-based and student-centered,” said all the Debre Berhan University schedule respondent lecturers. Therefore, visualizing the abstract and complex concepts together with students mutual interactions facilitate the internalization of the difficult topics of chemistry.
CONCLUSIONS AND RECOMMENDATIONS

Chemistry and technology are interdependent and advances in chemistry often lead to new technological discoveries. Therefore, if Chemists use appropriate technology, the learning of chemical phenomena and concepts becomes easy. The aim of this study was to indentify and determine how Technology Driven Pedagogy supports students’ understanding of complex and abstract concepts in chemical equilibrium learning.

The research took place at Debre Berhan University that caters for different students from diverse backgrounds and employs both traditional and student centered technique of teaching. In order for students to become qualified professionals in Chemistry they should receive clear and quality teaching. In dealing with these issues there must be appropriate learning environment.

The results of Chemical Equilibrium post-test indicated that students, who were taught by Technology Driven Pedagogy approach, were more successful than the students who were taught by student-centered method. Students’ interest and comprehension ability were increased. Moreover, students clearly understood complex concepts of Chemistry because of using 3D, dynamic picture scheme, sketch and films. It can be concluded that computer based education is more effective than student centered on students’ perception towards Chemical Equilibrium. Complexity is a key factor in casting a shadow for students’ understanding of chemical equilibrium; we need to be alert to concepts that are subject to misinterpretation by our students.

Therefore, the development and application of TDP learning environments is feasible based on expertly engineering development of methodologies and is highly recommended for use by Chemistry lecturers in particular and science educators in general.
REFERENCES
DEVELOPMENT OF ONTOLOGICAL KNOWLEDGE REPRESENTATION: LEARNING HYDROCARBONS WITH DOUBLE BONDS AT THE SECONDARY LEVEL

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Corresponding author e-mail: tamara.hrin@neobee.net

ABSTRACT

This paper presents the development of an ontological knowledge organization and representation, and explains how application of appropriate methods for its visualization can lead to meaningful learning. We have applied systemic diagrams (SD) as a method of visualizing ontological knowledge organization. Seven ontological models for "Hydrocarbons with double bonds", following the development from concept map to systemic diagram, are constructed. Chemical properties of alkenes are particularly elaborated and represented as a final systemic diagram (SD$_f$). [AJCE, 3(2), June 2013]
INTRODUCTION

Ontological Knowledge Organization and Representation

Learning and knowledge are closely related concepts. The way in which the student learns determines the type of resulting knowledge (1) or results in the corresponding quality of the acquired knowledge. During learning, i.e. acquisition of knowledge, students are faced with the problem of understanding of a new domain, as there are many new relationships among concepts, facts, or rules that seem arbitrary and confusing (2). The question is, what is a good method of teaching and learning by which one can overcome the problems of lack of understanding of the new domain, and how to facilitate learning of concepts which are often numerous and abstract to the students? In order to answer these questions, we will look at the process of acquiring knowledge.

Knowledge acquisition process requires three stages: knowledge elicitation, knowledge analysis, and knowledge representation (3). Successful analysis and knowledge representation require an efficient way of organizing knowledge which will allow development of knowledge base (Figure 1). How a knowledge organization enables the creation of rich knowledge base, and what is the connection among knowledge elicitation, analysis, representation and organization, can be explained by Piaget's model of equilibration and cognitive schemes (4).

Piaget's model of equilibration describes a process in which people accept new information from the environment (knowledge elicitation), how they perceive and experience them (knowledge analysis), and finally, how they integrate these new information into their own knowledge base, through cognitive schemas (knowledge organization). Piaget pointed out the existence of cognitive schemes that are developed and formed through the coordination and internalization during the activity with given objects (5). An object can be integrated into the
scheme, during the action, which has been carried out on it (4). These schemes are the result of a process of adaptation to the complex experience (actions), such as interpretation and integration of objects we are facing. In schema-based knowledge objects are linked together and organized into sophisticated hierarchical structures (6). As cognitive units, schemas represent a higher level of organization than a simple collection of lower-level components (6). Sweller (7) has emphasized that knowledge and intellectual skills based on knowledge are highly dependent on the scheme acquisition.

Brinkman (8) has emphasized that in order to be useful, knowledge must be organized in the way to facilitate understanding and to develop problem-solving skills. Novak (9) has pointed out that the quality of learning depends on the conceptual richness of new material that needs to be learned, as well as on the quality and quantity of relevant knowledge organizations. So, organization of knowledge must be clear and understandable, to enable correct learning of new facts, to provide connections, as well as drawing conclusions based on the adopted facts, linking new and previously acquired facts. The final goal of learning process is integration of new knowledge into the system of previously acquired knowledge, and it is the main characteristic of meaningful learning, which is described by Ausubel (10) and Novak (11).

In the opinion of Fahmy and Lagowski (12), Ausubel's important contribution is distinction that he has observed between mechanical (rote) and meaningful learning. By Ausubel (10), meaningful learning is manifested in students if they unarbitrarily and essentially connect new concepts with those already adopted. And rote learning occurs when material which has been taught does not have an established relationship with the previously learned. Figure 1 shows the relationship between good knowledge organization and meaningful learning, which
are linked by the fact that they enable the scheme acquisition, leading to the integration of new knowledge into the system (base) of knowledge.

Figure 1: Relationship between good knowledge organization and meaningful learning

The question is how to provide the organization and representation of knowledge that can contribute to meaningful learning? To achieve good organization (representation) of knowledge, an appropriate method of teaching and learning can be applied. A good method of teaching must create rich and stable knowledge base system, and in chemistry this system comprises: chemical scientific theories, chemical laws, chemical scientific concepts and facts (13).
Kim and coauthors (14) have pointed out that knowledge organization has a fundamental role in the successful knowledge representation, and thus allowing application of knowledge. This group of authors describes use of ontologies for knowledge organization in a given domain. In the context of computer science, ontologies have been applied in the field of artificial intelligence in order to facilitate knowledge sharing and reuse of acquired knowledge (15). Soon, ontologies have gained great popularity. They have been expanded to the fields of knowledge engineering, natural-language processing and knowledge representation. The reasons for the rapid extension of application of ontologies are providing understanding in domain knowledge and clear communication between users (students) and application system (ontological model).

In the context of knowledge representation, ontology is defined as a formalization of the concepts of application domain (16), or as a specification of conceptualization (17). Ontology presents concepts of domain of interest, and relationship that are relevant to the particular application domain, creating a vocabulary of that domain. In the ontological knowledge organization, given concepts are grouped into classes, and classes are often arranged in the form of hierarchical set. To visualize the ontological knowledge organization, to design and construct ontologies, a variety of graphical tools – ontological models (ontological diagrams), might be applied. Kim and coauthors (14) use knowledge maps, noting that for the same purpose concept maps, semantic networks, Petri nets and structures named frame can be used. Zipp et al. (18) have stated strategy which involves usage of mnemonics, traditional hierarchical note taking, charts, scientograms, mind maps, and concept maps.

In the course of learning complex, unknown contents, we are passing through the appropriate stages of learning. The first phase occurs with storage of isolated concepts, and therefore we do not have schemes for interpretation and integration of pieces of information we
are facing (19). At this stage, during the memorization of the more or less isolated concepts, mnemonics can be useful. As learning progresses, these concepts are grouped and organized, and then integrated into higher order structures. At this stage, mnemonics does not play an essential role. Instead of mnemonics, several other types of knowledge organization can be more useful, for example hierarchies and matrixes (19). Then the nature of learning is changing, starting from a completely linear manner to more associated manner of knowledge representation.

But, all of these techniques, which tend to foster and promote meaningful learning, more or less develop concepts in a linear manner. In hierarchical note taking, concepts are listed in categories, e.g. from superior to inferior, using the spatial model from left to right. With the mind map, students use visuospatial, rounded relationships, moving with branching from central theme (central concepts) to peripheral concepts (18). Chen (20) has been using ontologically modeled concept maps – graphical structures in which concepts have been shown in the vertices of the diagram, and relationships between them have been emphasized placing arrows (21) in the appropriate directions.

In constructing concept maps, we start from the top, where most general concepts are placed, moving to the lower parts where more specific concepts are placed, linking them with arrows. Based on his research, Chen (20) has concluded that concept maps could be applied for adoption and mastering difficult material for learning, establishing connections between new and previously acquired concepts. However, it should be noted that in concept maps relationships among concepts are linear, and therefore all existing relations between them can't be seen. Fahmy and Lagowski (22) point out that it is difficult to achieve a global view of the collection of linearly arranged concepts. To overcome this lack of concept maps, they introduce systemic arrangements of concepts, where all relations between them are set out explicitly (22).
Interest of Fahmy and Lagowski for concept maps is reflected in structural similarities with systemics, but we want to emphasize that these two strategies have a common root – the ontological aspects of presenting the concepts in the domain knowledge. The difference is that systemics are able to provide more global view of the concepts and their relations, because they can be taught of as a "closed concept map cluster" (23), and thus allow better assimilation of knowledge, by storing knowledge in long-term memory. Observing the relations shown in Figure 2, we can conclude that systemics are very favorable method for organizing and representing knowledge because of connection of new information with those already adopted. Thus we can provide a meaningful learning for students who apply this teaching and learning method in the learning process. It can be said that systemics have taken all good features of concept maps, while at the same time improving or eliminating their disadvantages (13).

![Systemic diagram](image)

Figure 2: *Systemic diagram (SD) with five concepts*

**METODOLOGY**

Learning organic chemistry is often confusing to students who find it as a huge maze of structural formulas and reactions, which in their view can be mastered only by mechanical memorization. On the other hand, organic chemists the same field find very well-ordered, with
elegant simplicity (24). To achieve such knowledge organization, all concepts in a given domain must be represented in the right way. It means that concepts should be clearly stated, with all necessary features, and properly established relations of these concepts with others in the same domain. Considering this problem, we have chosen Systemic Approach to Teaching and Learning Chemistry [SATLC] (12, 22-24, 26-28) as a method of representing concepts, relying on the Fahmy and Lagowski's statement that systemic diagrams (SD) facilitate the understanding of relationships between concepts in a broader sense (23). SD is the key for creating teaching units, in accordance with the principles of the SATL method (26).

In this paper, SATL method is applied in the part of one chemical teaching topic – "Hydrocarbons with double bonds". The scope of chosen concept satisfies high school level. As part of this teaching topic, students learn alkenes and dienes as acyclic hydrocarbons with double bonds, and cycloalkenes and arenes as cyclic ones. Each of these classes of organic compounds is characterized by certain type of chemical reaction. Classification of hydrocarbons with double bonds, as well as types of their characteristic chemical reactions, is linearly shown in Figure 3.

![Figure 3: Concept map for hydrocarbons with double bonds](image-url)
For alkenes, characteristic reactions are addition and oxidation. Combining fields in which we indicate alkenes, with the fields in which we indicate addition and oxidation, we obtain two unknown relation: 1? - *How alkenes are associated with the reaction of addition*, and 2? - *How alkenes are associated with the reaction of oxidation* (Figure 4).

Figure 4: *Concept map for hydrocarbons with double bonds, which is extended by connecting alkenes with reaction of addition and oxidation*

After completion of this teaching topic, students need to know (*the goals of learning*):

a. what type of reaction corresponds to each class

b. which relationships connect one class with other classes of hydrocarbons with double bonds
c. which relationships connect that class with the previously learned classes of organic compounds. Previously learned classes of organic compounds are alkanes, cycloalkanes, and alkyl halides.

To achieve these goals, we first need to display a concept map, which will specify the scope of desirable concepts. Concept map includes concepts such as: selected class of organic compounds (alkenes), types of chemical reactions and products of a given chemical reactions (Figure 5).

![Concept map which presents chemical properties of alkenes](image)

**Figure 5: Concept map which presents chemical properties of alkenes**

Using a concept map from Figure 5, students can learn the chemical properties of alkenes, however, they cannot reveal the deeper connection between the resulting products. So, using a given concept map, students can meet goal a., but cannot meet goal b. or c. In order to accomplish the goal c., it is necessary to set the relationships between the obtained products. In
such way we construct the initial systemic diagram (SD₀, Figure 6), which assures an equal starting point for all students (26). After all students have mastered the characteristic chemical reactions of alkenes (using concept map), they are now ready to move to the next step of learning process - connecting all concepts in the domain.

![Figure 6: Initial systemic diagram (SD₀) which presents chemical properties of alkenes and unknown relations between obtained products](Image)

When students, together with their teacher, have discovered all unknown relationships outlined in Figure 6 (from unknown relation 1 to unknown relation 8), we are getting the final systemic diagram, SD₁ (26). So teaching unit ends with SD₁ (Figure 7), in which all relations among given set of concepts are clearly indicated. Specification of unknown relationships from Figure 6 is shown in Table 1.
Table 1: Specification of unknown relationships from Figure 6

<table>
<thead>
<tr>
<th>Number</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>cc H₂SO₄ / 180 °C</td>
</tr>
<tr>
<td>2.</td>
<td>H₂O</td>
</tr>
<tr>
<td>3.</td>
<td>HX</td>
</tr>
<tr>
<td>4.</td>
<td>KOH</td>
</tr>
<tr>
<td>5.</td>
<td>X₂ / hυ</td>
</tr>
<tr>
<td>6.</td>
<td>Combustion; O₂</td>
</tr>
<tr>
<td>7.</td>
<td>cc KOH</td>
</tr>
<tr>
<td>8.</td>
<td>1. CH₃COOH; 2. NaOH</td>
</tr>
</tbody>
</table>

Figure 7: Final systemic diagram (SDₜ) which presents chemical properties of alkenes and all existing relations among given set of concepts
DISCUSSION AND FURTHER APPLICATIONS

In future work, in order to meet the goal b., we should likewise construct systemic diagrams for dienes, cycloalkenes and arenes. Then, it would be able to contemplate relations among all classes of hydrocarbons with double bonds.

However, the aim of this study was to consider the SD from the perspective of the ontological knowledge representation and organization, and to show the benefits of their application in comparison to other methods of ontological knowledge representation. In order to determine the true methodological value of our systemic diagrams in the teaching process in high school, they should be tested in the form of the experimental teaching, where diagrams are used as an instructional and learning means. However, since there are many papers which confirm the improvement of students’ achievement when they use systemic diagrams in learning process (12, 22, 23, 27, 28), we'll look back for some new additional facts. It would be very interesting to determine whether there is a correlation between student achievement and cognitive load, comparing students who learn with systemic diagrams and those who learn without them. Establishing this relationship is going to be one of the main tasks of our further research.

REFERENCES

**ACKNOWLEDGEMENT**

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USING STEREOCHEMISTRY MODELS IN TEACHING ORGANIC COMPOUNDS NOMENCLATURE: EFFECT ON SENIOR SECONDARY STUDENTS’ PERFORMANCE IN RIVERS STATE OF NIGERIA

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ABSTRACT
The purpose of the study was to find out the effect of stereochemistry models on students’ performance on organic compounds nomenclature. The study was a quasi-experimental design. The sample of the study was two hundred and sixty senior secondary 1 and 2 chemistry students in four intact classes of a University Demonstration School. The sample constituted 134 students in the experimental group and 126 students in the control group. Lesson plan of organic nomenclature using Stereochemistry Models, lesson plans using Chart Models and Organic Compound Nomenclature Test were the three instruments used in the study. Overall findings of the study showed among others that the control group (Chart Model) experienced more problems in organic nomenclature than the experimental group (Stereochemistry Model); the treatment had significant effect: students taught using Stereochemistry Models performed better than those taught using Chart Model; SS 2 students performed better than SS 3 students in the Organic Nomenclature Test. These findings were discussed in the study. [AJCE, 3(2), June 2013]
INTRODUCTION

Chemistry is a branch of science which deals with the composition, properties and uses of matter. It probes into the principles governing the changes that matter undergoes. According to West African Examinations Council (1), the sole organizer of Senior Secondary School Certificate Examinations for West African Countries, a chemistry curriculum should, amongst other objectives,

(i) facilitate a transition in the use of scientific concepts and techniques in integrated science;

(ii) provide the students with basic knowledge in chemical concepts and principles through efficient selection of content sequencing;

(iii) show chemistry in its inter-relationship with other subjects;

(iv) show chemistry and its link with industry, everyday life and benefits;

(v) provide a course which is complete for pupils not proceeding to higher education while it is at the same time a post-secondary chemistry course.

Knowledge of chemistry through its content and processes has enabled us to produce good water for drinking, food, improved health care delivery through the production of drugs, production of various materials for construction in industries, roads, automobiles and in our homes. Chemical knowledge is also useful in solving problems resulting from human interaction with the environment like water, air and land pollution.

Despite the relevance of the knowledge of chemistry to the society, achievement of students in chemistry as measured by their scores in Senior Secondary School Certificate Examinations has been very poor (1-3) up to the present day.
Apart from the heavy conceptual demand on the memory capacity required of the students to study chemical content, one additional problem is that of naming chemical compounds especially in organic chemistry. Chief Examiners’ Reports (1) have continuously indicated that candidates’ poor performance in organic nomenclature has been their inability to write the correct names and structures of the organic compounds. The problem with chemical nomenclature has been reported with students elsewhere in the world (4).

**PURPOSE AND BASIC QUESTIONS OF THE STUDY**

The main purpose of this study is to find out how to help the students remedy the problem identified in the previous section.

Two major sources of the problems encountered by the students in learning nomenclature are from the chemistry textbooks and from the teachers. Some chemistry textbooks are not consistent with the names given to organic compounds. Some of these texts go with old names side-by-side with the IUPAC names (5). For instance, CH₃CH₂OH or C₂H₅OH stands for ethanol, ethan-l-ol and ethyl alcohol in some textbooks and they are the same. Why phenol C₆H₅OH or ![phenol_structure] and not benzene alcohol? These and lot more pose doubt in the memory of the students as they learn organic nomenclature.

Some chemistry teachers are not well grounded in naming organic compounds. They cannot give what they do not have. By implication, they cannot teach what they do not know. So where do the students go from here? They are left in their own imagination. However, good teachers have employed the use of models especially in teaching nomenclature in stereo
chemical compounds. These are compounds whose molecules have three dimensional spatial configurations. Some stereochemistry models include ball-and-stick which are very useful in studying the stereochemistry or the spatial arrangement of carbon atoms of relatively complex organic molecules. These are commonly used in teaching nomenclature in our schools. Because of the nature of the organic content of general secondary school chemistry which is not too wide and detailed as undergraduate chemistry, the use of ball-and-stick model seem to suffix in demonstrating organic structures. This is why this model appealed to us for usage in this study.

Although this model is commonly being used in helping students learn organic compounds, we are not sure if the efficacy of this model in learning has been investigated. We are yet to sight such studies. This is why we thought it wise to carry out an investigation to find out how students will perform in naming organic compounds after being taught using the ball-and-stick model and compare such performance with mere teaching with sketches of structures on charts or chalkboard. We are also conscious of gender factors in our classrooms as pertaining to learning achievement and so we included it in our study. Specifically, the study attempted to provide answers to the following research questions, namely;

1. What difficulties do students have in naming organic compounds after they are taught using ball-and-stick model and chart?

2. What is the performance of the students in naming organic compounds after they are taught using ball-and-stick model and chart?

3. Considering class level, what is the performance of the students in naming organic compounds after they are taught using ball-and-stick and chart?

4. To what extent will gender influence the performance of the students in naming organic compounds after they are taught using ball-and-stick and chart?
It was also hypothesized in the study that:

$H_01$: There will be no significant difference between the mean performance of students taught naming organic compounds using ball-and-stick and that those taught with chart.

$H_02$: There will be no significant difference between the mean performance of students taught naming organic compounds using ball-and-stick and that of those taught with chart with respect to class level.

$H_03$: There will be no significant difference between the mean performance of students taught naming organic compounds using ball-and-stick and that of those taught with chart with respect to gender.

**METHODODOLOGY**

The study is a quasi-experimental study of the type

\[ O_1 \times O_2 \]
\[ O_3 \times O_4 \]

Involving an experimental group (teaching organic nomenclature using ball-and-stick) and a control group (using chart in teaching nomenclature). Independent variables of the study were the teaching methods while the dependent variable was the performance of the students in naming organic compounds. Two intervening variables namely, class level and gender were considered in the study. The variables of the study are schematically represented in Figure 1.

![Variable Representation](image)

Fig.1: Schematic Representation of Variables (Arrows do not indicate causal relationship.)
Two hundred and sixty (260) year 2 and 3 Senior Secondary Chemistry students from four intact classes each of SS2 and SS3 from a University Demonstration School made up the sample of study. SS2 students were 140 while SS3 students constituted 120. Two classes each of SS2 and SS3 were randomly assigned to experimental and control groups. There were therefore two experimental groups and two control groups for SS2 and SS3 classes. Sample distribution according to class and gender is shown in table 1.

Table 1: Study Sample Distribution

<table>
<thead>
<tr>
<th>Group</th>
<th>Class</th>
<th>SS2</th>
<th>SS3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Boys</td>
<td>Girls</td>
<td>Boys</td>
</tr>
<tr>
<td>Experimental</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>34</td>
</tr>
<tr>
<td>Control</td>
<td>37</td>
<td>33</td>
<td>31</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>77</td>
<td>63</td>
<td>61</td>
<td>59</td>
</tr>
</tbody>
</table>

Three sets of research instruments were used in the study. They were (a) Lesson Plans of Organic Nomenclature using Stereochemistry Models (LPSM), (b) Lesson Plans of Organic Nomenclature using Chart Models (LPCM) and (c) Organic Compounds Nomenclature Test (OCNT).

In both LPSM and LPCM, students were taught the IUPAC rules (6-9) for naming organic compounds. Students were also taught the structures of the organic compounds to be named. Altogether ten lessons involving nomenclature of simple alkanes, alkenes and alkynes and derivatives were taught each for LPSM and LPCM. The difference between LPSM and LPCM was that in LPSM further illustration was done using the stereochemistry model to explain the spread of the atoms in space and the attempt to present what seem to be the real pictures of the molecules between atoms through the bonds.
OCNT was made up of forty test items requiring the students to provide the names of the organic compounds following the IUPAC rules. Three samples of the test items are given below.

1. Write down the name of the compound with the formula:

\[ \text{ClH}_2\text{CCH}_2\text{CH}_2\text{OH} \]

2. What is the IUPAC name of the compound?

[Diagram of the compound structure]

3. Give the name for the structure

[Diagram of the compound structure]

OCNT is a paper-and-pencil test and was timed to last for forty minutes. In scoring of OCNT each correct naming of the organic compounds in the test item was scored 2 marks while incorrect answer was scored 0. Maximum score was 80 marks while minimum score was 0 mark.

The instruments for the study were subjected to adequate scrutiny by three chemical educators who were already working on some aspects of organic compound nomenclatures. They provided some advice concerning the procedure for teaching the nomenclatures with or without the stereochemistry models. They also suggested that two research assistants should be trained to handle the teaching using the two sets of lesson plans. These suggestions were very useful in making amendments for the design of the study. The three chemical educators also
observed that the test items were within the reach of senior secondary students considering the content of their syllabus.

On this note, the test (OCNT) was administered on 20 SS2 chemistry students chosen from a Secondary School in a Local Government different from that of the school used for the study. The test was given to the students on two different occasions spaced by two weeks. The two sets of scores obtained were collated and Pearson’s Product Moment Correlation Coefficient formula applied to determine the reliability (r) of the OCNT. An r of 0.73 was obtained. Based on this coefficient, the test was considered to be reliable for use in the study.

The study was carried out in the students’ school. The authorities of the school were consulted and permission sought. The lessons were taught during the periods for chemistry in the timetable. Altogether ten weeks were used by the research assistants for both the experimental group and the control group. Before the teachings started, the students were pretested. After the teaching, testing also took place.

RESULTS

Data were analyzed and presented according to the research questions and hypotheses set for the study.

1. Difficulties encountered by the students in naming organic compounds

Nine observable difficulties were noted for both students taught with stereochemistry models and those taught with chart (see Table 2)
Table 2: Difficulties associated with naming Organic Compounds by students after teaching

<table>
<thead>
<tr>
<th>Difficulties</th>
<th>Experimental Group (use of stereochemistry Model)</th>
<th>Control Group (Use of Chart)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Inability to recognize the longest chain</td>
<td>f 37 (%)</td>
<td>f 48 (%)</td>
</tr>
<tr>
<td>2. Confusion arising from representation of straight carbon chains</td>
<td>25 (18.7)</td>
<td>20 (15.9)</td>
</tr>
<tr>
<td>Confused with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Inability to identify bonds when not inserted, for eg. CH₃CHOHCH₃</td>
<td>31 (23.1)</td>
<td>36 (28.6)</td>
</tr>
<tr>
<td>4. Inability to distinguish between functional groups for eg – CHO, COR</td>
<td>32 (23.9)</td>
<td>34 (26.9)</td>
</tr>
<tr>
<td>5. Difficulty in numbering of carbon atoms considering functional groups</td>
<td>37 (27.6)</td>
<td>37 (29.4)</td>
</tr>
<tr>
<td>6. Inability to number carbon atoms in a chain containing double and triple bonds</td>
<td>16 (11.9)</td>
<td>21 (16.7)</td>
</tr>
<tr>
<td>7. Inability to distinguish main compounds from derivatives</td>
<td>19 (14.2)</td>
<td>30 (23.8)</td>
</tr>
<tr>
<td>8. Not attaching importance to the use of hyphens and commas in names eg 2-methyprop-2-ene or 1,2-chloroethane</td>
<td>30 (22.4)</td>
<td>30 (23.8)</td>
</tr>
<tr>
<td>9. Inability to name compounds according to cis-,trans-isomeric transformations</td>
<td>27 (20.1)</td>
<td>32 (25.4)</td>
</tr>
</tbody>
</table>

f means frequency
Information in Table 2 revealed that apart from ‘confusion arising from representation of straight carbon chains’ where control group had lesser percentage (15.9%) than experimental group (18.7%), in the rest of the eight identified difficulties, more students in the control group (use of chart) experienced difficulties than those in the experimental group where stereo-chemical models were used in teaching them.

2. Students’ Performance in Organic Compounds Nomenclature

Analysis of Covariance (ANCOVA) was carried out using pretest and post test scores of both the experimental and the control groups. The results of are displayed on table 3.

Table 3: ANCOVA of Pre-test and Post-test Scores of Experimental and Control Groups

<table>
<thead>
<tr>
<th>source</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean</th>
<th>F</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected mode</td>
<td>4669.717</td>
<td>2</td>
<td>2334.858</td>
<td>59.051</td>
<td>.000*</td>
</tr>
<tr>
<td>Intercept</td>
<td>6621.445</td>
<td>1</td>
<td>6621.445</td>
<td>167.464</td>
<td>.000*</td>
</tr>
<tr>
<td>Pretest</td>
<td>1.291</td>
<td>1</td>
<td>1.291</td>
<td>.033</td>
<td>.857ns</td>
</tr>
<tr>
<td>Treatment</td>
<td>4666.281</td>
<td>1</td>
<td>4666.281</td>
<td>118.015</td>
<td>.000*</td>
</tr>
<tr>
<td>Error</td>
<td>10161.683</td>
<td>257</td>
<td>39.540</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>804194.000</td>
<td>260</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected total</td>
<td>14831.400</td>
<td>259</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant beyond 5% level, ns = not significant

It is worth noting that comparison of the pretest scores of the experimental and control groups did not yield a significant difference, but the effect of the treatment was highly significant, F=118.015, df=1/259, p<.05.

Performance of the students in Experimental and Control Groups:

Post test scores of both the experimental and the control groups were compared and H₀₁ tested. The findings are presented in Table 4.
Table 4: Performance of Experimental and control groups in Naming organic compounds

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>X</th>
<th>SD</th>
<th>t-value</th>
<th>df</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>134</td>
<td>59.21</td>
<td>7.98</td>
<td>11.01</td>
<td>258</td>
<td>Significant at P &lt;.05</td>
</tr>
<tr>
<td>Control</td>
<td>126</td>
<td>50.73</td>
<td>3.68</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results in Table 4 show that students taught using the stereochemistry models performed better than those taught using the chart. The difference in performance was significant at p<.05, t=11.01, df=258 (see H₀₁).

Class Level and the Performance of the students in Naming Organic Compounds

Performance of the students according to the mode of instruction with respect to class level is shown in Table 5. Related hypothesis (H₀₂) was also tested.

Table 5: Performance of Experimental and control groups with respect to class level

<table>
<thead>
<tr>
<th>Group</th>
<th>Class</th>
<th>N</th>
<th>X</th>
<th>SD</th>
<th>t-value</th>
<th>df</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>SS2</td>
<td>70</td>
<td>59.71</td>
<td>8.65</td>
<td>0.76</td>
<td>132</td>
<td>ns</td>
</tr>
<tr>
<td>Control</td>
<td>SS2</td>
<td>64</td>
<td>50.63</td>
<td>7.20</td>
<td>-0.34</td>
<td>124</td>
<td>ns</td>
</tr>
<tr>
<td>Experimental</td>
<td>SS3</td>
<td>70</td>
<td>59.71</td>
<td>8.65</td>
<td>8.18</td>
<td>138</td>
<td>*Significant at p &lt; .05</td>
</tr>
<tr>
<td>Control</td>
<td>SS3</td>
<td>64</td>
<td>50.63</td>
<td>7.20</td>
<td>7.22</td>
<td>118</td>
<td>*Significant at p &lt; .05</td>
</tr>
</tbody>
</table>

Results in Table 5 show that for experimental SS2 and SS3, and control SS2 and SS3, there are no significant differences in the performance of the students. But for experimental SS2 and control SS2, and experimental SS3 and control SS3 significant differences in the performance of the students exist. These are t=8.18, df=138 and t = 7.22, df = 118 respectively.
Gender and the Performance of the Students in Naming Organic Compounds

Performance of the students according to the mode of instruction with respect to gender is displayed in Table 6. Related hypothesis (H₃) was also tested.

Table 6: Performance of Experimental and control Groups with respect to gender

<table>
<thead>
<tr>
<th>Groups</th>
<th>Gender</th>
<th>N</th>
<th>X</th>
<th>SD</th>
<th>t-value</th>
<th>df</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>Boys</td>
<td>70</td>
<td>59.71</td>
<td>8.65</td>
<td>0.76</td>
<td>132</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>64</td>
<td>58.66</td>
<td>7.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Boys</td>
<td>68</td>
<td>50.58</td>
<td>3.51</td>
<td>-0.49</td>
<td>124</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>58</td>
<td>50.90</td>
<td>3.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>Boys</td>
<td>70</td>
<td>59.71</td>
<td>8.65</td>
<td>7.13</td>
<td>136</td>
<td>Significant at P &lt; .05</td>
</tr>
<tr>
<td>Control</td>
<td>Boys</td>
<td>68</td>
<td>50.58</td>
<td>3.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>Girls</td>
<td>64</td>
<td>58.66</td>
<td>7.20</td>
<td>6.87</td>
<td>120</td>
<td>Significant at P &lt; .05</td>
</tr>
<tr>
<td>Control</td>
<td>Girls</td>
<td>58</td>
<td>50.90</td>
<td>3.89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results in Table 6 show that experimental boys and girls performed better than the control boys and girls. The difference between the mean scores (X) are significant at 5% level as observed in t=7.13, df=136 and t=6.87, df=120 respectively.

DISCUSSION OF FINDINGS

The findings of this study seem to be revealing how we teach organic compound nomenclature and how students learn. It appears that teachers do not emphasize the IUPAC rules guiding naming organic compounds. How else would one explain the difficulties students encounter in naming organic compounds, knowing well that these names connote the structures of such compounds. In turn, structures determine the type of reactions such compounds undergo.

It is shown in Table 2 that students encountered a number of difficulties while attempting to name organic compounds even when the teachers employed some instructional strategies to help
them. Experimental group students were taught using the stereochemistry models in addition to chart while the control group was taught with only the chart yet the difficulties were observed. Lesser percentage of the students taught using stereochemistry model than those taught using chart had difficulties. This seems to be encouraging the teachers to continue using model in teaching organic nomenclature.

One observation needs to be contemplated on. This is the “confusion arising from representation of straight carbon chains” where 18.7% of the experimental group encountered more difficulties as against 15.9% of the control group. It could be that straight chain of carbon atoms is better learnt when represented on the chart than when stereochemistry model is used. Obviously, ball-and-stick model arrangement of a C-C bond does not look like a straight line as indicated on a chart or on the chalkboard. The model arrangement is three-dimensional while the chart is one-dimensional. It would be wise for the teachers to improve on the combination of both the model and the chart in helping the students learn organic compound nomenclature. This perhaps assisted in the performance of the students in the experimental group and the control group because the treatments were significant beyond 5% level of significance, F=118.015, DF,1/257 (cf Table 3).

However, experimental group students performed significantly better than the control group students (cf Table 4). This finding seem to be pointing to the direction that teaching organic compound nomenclature is fruitful using stereochemistry model such as ball-and-stick. One good thing about ball-and-stick is that the atoms and functional groups are represented in colors and sizes compared with the sketches on the chart that appear to be mock forms of the compounds. Models are concrete and easily attract the attention of the learner to conceptualize the structure of the compound through the models. Students can be encouraged to acquire a
model box for their own which will enable them practice naming of organic compounds on their own. Besides, it is easy to improvise organic compound models using local materials in our environment, for example, clay, wax, starch and gum.

The useful role of using stereochemistry model in learning nomenclature of organic compounds is also observed when students’ class and gender variables were considered. In terms of the class, experimental S22 and SS3 students performed significantly better than the control SS2 and SS3 students (See Table 5). Use of the model was very important, but it was also found that experimental SS2 students had higher mean score (X=59.71) than the SS3 students (X=58.66) in naming the organic compounds. This was surprising. However, when the school’s subject diary was checked, it was found that SS3 students studied major part of nomenclature in SS2. They (SS3 students) seem to have forgotten the IUPAC rules for naming organic compounds. The SS2 students were currently studying the IUPAC rules of naming the compounds, so it was fresh in their memory when the study was carried out.

It was also revealed in the study that experimental boys and girls were significantly better than control boys and girls in naming organic compounds (see Table 6). Mean difference between the performance of the boys and that of the girls was not significant. Again, the use of stereo-chemical models in teaching nomenclature of organic compound proved very useful in learning the names and structure.

In conclusion, it is important to note that teachers make various attempts using different strategies in teaching chemical concepts including teaching organic compound nomenclature. Studies have also been conducted to show how such strategies and methods are paying-off in learning. It was not to our knowledge that a study like this present one has been conducted elsewhere. We are happy as chemistry teachers to have been involved in the study and to
encourage other chemistry teachers to use both the stereochemical model and the chart in teaching students names of organic compounds.

REFERENCES

THE PLACE OF PHILOSOPHY OF CHEMISTRY IN REDUCING CHEMICAL MISCONCEPTIONS

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ABSTRACT

This paper aims to forward a framework that can give an insight how philosophy of chemistry plays a role in reducing chemical misconceptions and be incorporated in the teaching-learning process of chemistry. It is concluded that epistemological explanations and representations specific to the macroscopic, microscopic and symbolic levels of chemistry are important elements for instructional representations to consider in the teaching-learning process of chemistry. [AJCE, 3(2), June 2013]
INTRODUCTION

There is a growing interest in the philosophy of chemistry and how it influences chemistry education. In fact, as Schummer (1) argues that:

The time of complaining about the neglect of the philosophy of chemistry is over now. With more than 700 papers and about 40 monographs and collections since 1990, philosophy of chemistry is one of the most rapidly growing fields of philosophy. Perhaps too rapidly, as it has become arduous for insiders to keep up-todate, troublesome for newcomers to approach the field and virtually impossible for outsiders to survey the main ideas (p.19).

Our intent in this paper is therefore not to discuss the neglect of philosophy of chemistry as was the case in early 1990s but to try to indicate the place of chemistry in challenging misconceptions in Chemistry teaching and learning.

Academics in the field argue that Chemistry can be “conceived as a ‘phenomenological’ science that only describes ‘phenomena’ which are apparent facts (2-3). This ‘phenomena’ is divided into physical and chemical phenomena (4). The physical phenomenon explains changes that involves from one form or state of substances to another form while the chemical phenomenon explains chemical change which involves a formation of new substances (4). Chemists engage in chemical phenomena through experimentation and explore the essential nature of chemistry to revise or develop their theories (3, 5).

It has been noted that (6) the philosophy of chemistry is a pragmatic and experimental science that combines both process philosophy and substance philosophy. Substance philosophy gives priority to entities or substances, and it explains that entities are permanent whereas process philosophy gives priority to the temporal state of entities and it asserts that only changes are permanent (6). Therefore, according to pragmatic philosophy of chemistry that combines both substance and process philosophy, chemistry characterizes and classifies chemical entities...
and substances and also describes changes that occur on chemical entities. It is concerned with characterizing substances, i.e. substance philosophy, and changes, i.e. process philosophy (6).

In sum, epistemological (philosophical) explanations and representations of chemistry argue that characterization of substances and changes in chemistry are made at macroscopic, microscopic and symbolic levels. It has been stated that “to meet students at their level and avoid misconceptions, chemistry educators are advised to pay careful attention to how these thinking levels are introduced” (7, p.50). Accordingly, instructional practices in chemistry have to be founded on these level-specific explanations and representations; otherwise students may face learning difficulties or develop chemical misconceptions.

A study (8) reported that creating association between microscopic model and macroscopic events were some sources of students’ learning difficulties and misunderstandings. Recently, it has been demonstrated (9) that some of the chemical misconceptions held by students in schools are related to the mixing of explanations and pedagogical representations of the macroscopic level chemical properties onto microscopic or symbolic chemical properties. Therefore, this paper attempts to forward a framework that can give an insight into how philosophy of chemistry plays a role in reducing chemical misconceptions and be incorporated in the teaching-learning process of chemistry. In doing so, the paper intends to initiate further discussions among chemistry educators in Africa and the world at large on the philosophy of chemistry and its pedagogical implications for teaching and learning chemistry.
CHEMICAL EXPLANATIONS, REPRESENTATIONS AND THEIR INFLUENCE ON PEDAGOGY OF CHEMISTRY

One of the epistemological arguments for the independence of chemistry is the theme of supervenience. Supervenience states that the properties of matter at macroscopic and microscopic level of chemistry have an asymmetric relationship (10-11). It means that chemical explanations about the properties of matter at macroscopic level are not exactly applicable to explain properties at its microscopic levels. For instance, graphite and diamond are constituted from carbon atoms, but explanations given about the properties of graphite or diamond couldn’t be applicable to explain the properties of carbon atoms. Hence, characterizing class of chemical identities (substances) and descriptions of chemical reactions or changes (process) should be made at three different representational levels (i.e. macroscopic, microscopic and symbolic levels). And the characteristics of chemical entities and temporal (reactions) nature of chemistry at each representational levels needs to be taught using pedagogy that go along with the nature of chemical explanations given to the respective representational levels.

It has been stated that (2) chemical knowledge or explanations are level specific. It means that chemical knowledge or explanation at macroscopic level is specific to this level, or it is not transferable to microscopic and symbolic level. For instance, explanation given to copper wire is specific to copper wire, it is not applicable to explain copper atom. The property of copper wire (macroscopic level) is malleable and ductile, but copper atom (microscopic level) is not.

Another example is that the identity of water in everyday life, such as melting and boiling point, color, odor, and shape are some of its macroscopic properties. But its chemical identities (properties) at microscopic level (i.e. water molecule and its geometry, the nature of the atoms
and bonds between these atoms) cannot be concluded from the observable (macroscopic) properties of water. Water molecule (H$_2$O) has a V-shape and forms a tetrahedral arrangement of water as a bulk system. Despite the asymmetric relationship between properties of identities of water molecule, H$_2$O (g) and water, H$_2$O (l) in a container, the macroscopic properties of water can be explained by its microscopic identities. This suggests that the instructional presentations used to teach water at the two levels should be different but carefully interconnected.

In general, although explanations at the macroscopic, microscopic and symbolic levels of chemistry are unanimously converged in explaining chemical phenomenon (12), the asymmetric relationship between the properties of macroscopic system and microscopic identity is maintained. Therefore, the epistemic explanations of the properties of matter in the teaching-learning process of chemistry have to be level specific. And the pedagogy of teaching chemical explanations has to be level specific; otherwise, it would be source of some chemical misconceptions.

Moreover, it is argued that knowledge about the world has a representational nature (13) and it has an epistemological origin. Chemistry knowledge has a unique nature and ways of representations. To this end, chemical phenomena are understood through macroscopic, submicroscopic and symbolic levels of chemical representations. This in turn affects the structure of modern chemistry (12).

However, the use of the same symbolic representations to both macroscopic and microscopic levels of chemical realities may become possible sources of chemical misconceptions. For instance, if we consider the burning piece of copper wire in a laboratory, we can have the following pedagogical representations:
Using the same pedagogical representations for both macroscopic and microscopic levels used either in (a) or (b) form may lead students to develop erroneous conclusion about the behavior of copper wire and copper atom. Because, students may think that color and state of copper wire and copper atom are the same while they are different. To reduce such sources of misconceptions, therefore, pedagogical representations and descriptions have to be specific to macroscopic and microscopic levels of chemical realities. And the representations used for copper wire and copper atom should not be the same.

In a study it has been reported that students argue that water disintegrates into H₂(g) and O₂(g) when it boils (14). This students’ explanation about the boiling of water seems linked to their understanding about the behavior of gases, which are not observable directly. This misconception is likely to be developed due to failure to show the interconnection between the bulk H₂O (l) and the molecule H₂O (g). However, if the teaching of the nature of water both at macroscopic and microscopic level uses distinct ways of representation, and show the relation and how molecule H₂O (g) aggregates to form the bulk water, students couldn’t develop such a misconception.

On top of representational nature of chemistry, the object of study, theories and language of chemistry education are defined by the ontological, epistemological and methodological views of chemistry. It has been stated that “the philosophy of chemistry addresses the scope of the phenomena that fall within the remit of chemistry, with the ontology of the entities of which those phenomena are thought to consist, and with matters of epistemology, the grounds of belief
on which such knowledge rests” (15, p.213). These philosophical views, which determine the scope and nature of chemistry highly influences the 21st chemistry education. In this connection Scerri (16) states that the philosophy of chemistry has an important influence on the teaching of chemistry and chemistry education in general.

Philosophy of chemistry is also influencing the thinking of modern chemical educators and the structure of modern chemistry. It is becoming a new pedagogical resource of chemistry teaching (2, 17). Some of the influential chemistry education metaphors have a philosophical origin. Mahaffy’s tetrahedral metaphor of chemistry education (7, 18), Johnstone’s Chemistry Triangle (19-21) and Jensen’s logical structure of chemistry (22) are some of the major chemical education models to some extent influenced by the philosophy of chemistry.

THE IMPACT OF LEVEL SPECIFIC EXPLANATIONS AND REPRESENTATIONS OF CHEMISTRY ON STUDENTS’ UNDERSTANDING

Erduran (10) states that one of the fundamental ways of thinking in chemistry is “the interplay of the microscopic, symbolic and macroscopic levels”. Thus, understanding chemistry involves connecting the macro, micro and symbolic world of chemistry (21, 23-24). If the interplay between the microscopic and macroscopic level of chemistry is not properly taught using best suit pedagogy of chemistry, students’ may develop a wrong understanding or misconception.

For instance, in connection to the relation between microscopic and macroscopic world of chemistry, it is noted that “all properties of organic molecules- physical, chemical, biological, and technological-depend on their chemical structure and vary with it in a systematic way” and “most physical properties of organic compounds depend functionally upon the number, kind, and
structural arrangement of the atoms in the molecule. The number and kind of atoms are both constant in isomers, and hence, the differences in their physical properties are due to structural relationships” (25, p.5715). This tells us that the macroscopic and microscopic identities of chemical substances are not identical. In other words, the chemical and physical properties of the macroscopic system are not exactly alike to the microscopic identities of the system. Chemical misconception about the scientific understanding of chemical substances could arise from lack of clear and distinct understanding between the macroscopic and microscopic identities and their respective chemical representations. Therefore, the descriptions and pedagogical representations need to be carefully designed not to allow the transfer of understanding of macroscopic properties of chemical phenomena onto understanding of its constituents (microscopic properties).

Accordingly, the instructional representations of the bulk (macroscopic system) have to be presented in a distinct way which shows the microscopic identities (the kind, and number) and how they are arranged in order to form the bulk. The instructional representations of microscopic identities and their constituents have to be distinct from the macroscopic system. If the macroscopic system and microscopic identities are represented with the same kind of symbols and pedagogical representations, students may fail to develop correct scientific understanding and fail to predict or explain macroscopic properties from microscopic identities. This might lead to the transfer of observation of macroscopic system to the microscopic identity which could results in students’ misconception.

Chemical misconceptions are possibly resulted from the mixing up of one level of chemical explanations onto the other. Most of the time studies show that the transfer of chemical explanations from one level to the other is common features of many chemical misconceptions.
Chemical explanations such as substances expand when they are heated and the volume of gases is related to pressure are examples of explanations for macroscopic level properties of matter. Based on these assertions, for example, “molecules expand when they are heated” and “pressure affects the shape of a molecule” were among some of the misconceptions held by students (14). Such misconceptions were resulted due to the transfer of explanations given to macroscopic properties on to microscopic identities. It is also noted (26) that students tend to assume/surmise phase changes occurring at the microscopic level from their observations of macroscopic changes of a substance.

There have been misconception reports which state that students understand that the boiling of liquid H\textsubscript{2}O (l) results into bubbles composed of air or H\textsubscript{2} or O\textsubscript{2} (14). This misconception is mainly linked to the application of macroscopic view of ideas that explain breaking the bulk material involves disintegrating the whole into its constituent parts. It tends to imply that if students think that the constituents of both liquid water and water molecule are the same, then they will apply the same explanations to both of them. Such lack of distinctions in students understanding about the constituents of liquid water and water molecule is a likely reason for their justification that boiling of H\textsubscript{2}O (l) resulted into bubbles composed of H\textsubscript{2} or O\textsubscript{2}. Moreover, students’ understanding of H\textsubscript{2} and O\textsubscript{2} as composition of air can also has an interfering effect on their understanding of boiled water.

In conclusion, failure to show the distinct nature and interconnections of chemical explanations and representations for the macroscopic, microscopic and symbolic level might become one major source of chemical misconceptions since such failure is inherently linked to the nature of chemistry.
PEDAGOGICAL IMPLICATIONS OF THE PHILOSOPHY OF CHEMISTRY TO REDUCE MISCONCEPTIONS

The philosophy of chemistry is an important tool to characterize chemical knowledge and its representational nature. It can be a good instructional tool to describe and connect chemical knowledge at macroscopic, microscopic and symbolic levels. The pedagogical explanations and representations have to be specific to each level of chemical realities and carefully designed to show the interconnection among the levels. Therefore, the chemical misconceptions that could result from the interference of knowledge from explanations about one representational level or explanation onto the other could be reduced if the philosophy of chemistry and its pedagogical influences are incorporated into teacher education program as part of pedagogical knowledge in pedagogical content knowledge (PCK) for chemistry education.

Given the fact that we are now living in the 21st century where the century’s skills are highly related to technology, it would be important to incorporate the philosophy of chemistry and its pedagogical influences into teacher education program as part of technological pedagogical content knowledge (TPCK). Such an approach is already conceptualized (27) and attempts are under process to fully design and implement the approach in Chemistry.

What are your views in relation to the philosophy of chemistry and its influence on teaching and learning of chemistry in particular and chemistry education in general? Please share your views as feature articles, letter to the Editor, etc in our Journal (African Journal of Chemical Education, AJCE).
REFERENCES
OUT OF SIGHT, OUT OF MIND?

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Women recover water from a well in Niger, within an FAO project to boost agro-pastoral production. ©FAO/Giulio Napolitano

Worldwide, 2.5 billion people depend solely on groundwater for their daily needs. Hundreds of millions of farmers irrigate their fields with groundwater to produce food for the masses. Yet experts consider that few, if any, of the world’s aquifers are being managed sustainably or equitably. The truth is that groundwater science, law and management are still in their infancy. Incredible as it may seem, we know much more about the planet’s oceans, lakes
and rivers than we do about the lifeline beneath our feet. This hasn’t prevented us from pumping it with growing voracity.

The Groundwater Governance Project aims to raise awareness of the paramount importance of managing the planet’s aquifers sustainably, in order to influence political decision-making and thereby avert the impending water crisis. The last of five regional consultations, that for 22 countries of the UN Economic Commission for Europe (UNECE\(^1\)), concluded in The Hague on 19–21 March 2013.

The Groundwater Governance Project was initiated in September 2011 by FAO, UNESCO, the World Bank and the International Hydrological Association (IAH), which are contributing US$2.7 million to the project. The Global Environment Facility (GEF) is providing a further US$1.75 million. Via a vast consultation, the three-year project intends to develop a Global Framework for Action targeting policy-makers and stakeholders. Eleven thematic papers have been prepared for these consultations to highlight key issues.

The Global Framework for Action will consist of a set of governance tools that include policy options, legislation, regulations and customary practices. In a nutshell, good groundwater governance is the art of coordinating administrative procedures and decision-making at different jurisdictional levels, one of which may be global. It lays the foundations for management practices that ensure broad participation, transparency, data- and information-sharing and conjunctive use (see box).

The lack of effective governance is one of the main causes of groundwater depletion, aquifer pollution and inequitable allocation. As needs and priorities tend to vary from one

\(^{1}\) See: www.unece.org/oes/member_countries/member_countries.html
locality to another, UNESCO convened five regional consultations\textsuperscript{2} between April 2012 and March 2013 with local groundwater experts, agencies, ministries and other stakeholders, in order to ensure that local concerns fed into the Global Groundwater Governance Diagnostic. This diagnostic will then serve as the basis for the Global Framework for Action.

**AFRICA’S BLUE GOLD**

At the regional consultation in Nairobi (Kenya) in May last year, David Stower, Permanent Secretary of the Kenyan Ministry of Water and Irrigation, said that ‘we need to stop looking at groundwater only in emergency situations and as a last resort. This is a narrow view that needs to be addressed and reversed,’ he said, ‘in order to fully apply the principles of integrated water resource management. The sub-Saharan region faces several challenges,’ he added, ‘including poor understanding of groundwater regimes and poor and inadequate data and information.’ He concluded by saying, ‘I hope that this very important regional meeting will outline practical solutions to address the unique groundwater challenges facing our region.’

Two years after the worst drought in 60 years, some 12 million people are at risk of starvation in northern Kenya and parts of Ethiopia and Somalia. Within UNESCO’s Groundwater Resources Investigation for Drought Mitigation in Africa Programme (GRIDMAP), experts have spent the past year mapping the location of groundwater using WATEX remote-sensing technology, in order to bring the weakened population a sustainable water supply. In parallel, Kenya has launched a Regional Groundwater Training and Research

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\textsuperscript{2} Latin America and the Caribbean (Montevideo, Uruguay, 18–20 April 2012), sub-Saharan Africa (Nairobi, Kenya, 29–31 May 2012), Arab States (Amman, Jordan, 8–10 October 2012), East and South Asia and the Pacific (Shijiazhuang, China, 3–5 December 2012), Europe, Western and Central Asia and North America (The Hague, Netherlands, 19–21 March 2013)
Centre, under the auspices of UNESCO, to improve the long-term management of East Africa’s aquifers.

Although Kenya is considered a water-scarce country, with about 647 m³ water per capita per year, the Ministry of Water and Irrigation cited studies which show that Kenya may have up to 60 billion m³ of groundwater potential that simply needs locating. ‘Groundwater’s advantages are numerous.’ said Kenya’s Assistant Minister, Fednand Waititu, in Nairobi. ‘Its occurrence in many places, the speed with which it can be developed, the relatively low capital cost of development, its drought resilience and ability to meet water needs on demand all make it a critical component of the rural water supply and for small towns, as well as for domestic water, irrigation, industrial and commercial uses.’ In Kenya’s 2009 census, 43% of rural and 24% of urban households identified a spring, well or borehole as being their main source of water.

Kakuma Refugee Camp in Turkana (Kenya), which now has access to a sustainable water supply, thanks to a UNESCO project which identified where to drill boreholes. These are now being drilled across the drought-stricken region. ©UNESCO
SIGNS OF POOR GOVERNANCE: OVERMINING AND POLLUTION

Groundwater is the source of nearly half of all drinking water in the world and represents about 43% of water used in irrigation. Over the past 50 years, groundwater abstraction has tripled, thanks to the widespread availability of energized pumping. Agriculture is the dominant user but pumping in and around urban areas can be even more intensive.

The decision whether or not to turn on a groundwater pump seems difficult to regulate. This is because access to groundwater is perceived as an essentially private concern, even though most jurisdictions define all water as being a ‘public’ good. The users are an identifiable group, however: those with access to a pump. If you add to this group those who spread chemical fertilizers and pesticides, extract oil, gas or minerals, dispose of untreated or dangerous (nuclear, chemical, etc) waste, or build underground (tunnels, transport systems, sewerage systems, etc), almost everybody bears some responsibility for the quality of groundwater.

This arguably makes protecting aquifers from surface pollution a more difficult governance issue than groundwater pumping. Studies conducted by UNESCO in Abidjan (Côte d’Ivoire) found concentrations of nitrates, ammonium and aluminium in groundwater in excess of WHO standards for drinking water. This chemical pollution had been caused by the use of pesticides and fertilizers in industrial plantations of pineapple, rubber and palm oil. In 2002, UNESCO’s Nairobi office initiated a joint project with UNEP to assess the impact of pollution on aquifers in Abidjan and eight other major African cities. The project developed methodologies for assessing groundwater vulnerability and identifying pollution hotspots and major threats. It also set up an early warning system involving a network of African scientists and alerted decision-makers in the public and private sectors to the dangers of indiscriminate waste disposal.

3 See A World of Science: http://unesdoc.unesco.org/images/0015/001516/151633e.pdf
It is always easier to solve a problem of pollution when there are good lines of communication. In the Indian State of Tamil Nadu, the aquifer was being contaminated by chromium waste from a local chemical company. Thanks to a dialogue between researchers and decision-makers, the company has since reformed its practices. In the city of Hyderabad, water was being polluted by the immersion of large Ganesh idols during a religious festival. A respectful dialogue with the local community resulted in the extended immersion of idols being replaced by a quick dip!

Promoting conjunctive use in Kenya

Kenya has spent five years developing an Integrated Water Resources Management and Water Efficiency Plan. The plan integrates a number of recommended governance practices, including a broad stakeholder consultation process, decentralized management and conjunctive use.

Conjunctive use refers to managing groundwater and surface water as a single entity, rather than as two separate sectors. Conjunctive use does not necessarily mean that both waters are used simultaneously, as groundwater can compensate during dry periods for the seasonal nature of rivers. Nairobi, Nakuru, and Machakos already operate conjunctive use schemes but that these sometimes bear a closer resemblance to a coping strategy than a planned approach to meeting water demand.

The lack of rational land use planning has meant that attempts to restrict abstraction from the Nairobi aquifer system have come up against indifference, commercial interests and a building boom. Moreover, the poor level of compliance by water users with respect to water permits and the payment of water-use charges makes water allocation an uncertain exercise at best.

The construction of the Kiserian Dam to supplement existing groundwater supplies to several Kenyan towns and cities is a conjunctive use scheme. The private commercial irrigation sector also often uses surface water and groundwater conjunctively, as for example in the Naivasha and North West Mt Kenya areas.

DEEP-SEATED CHALLENGES

Deep-seated aquifers (beyond 500 m) can act as a buffer against climate change, as they are isolated from the active hydrological cycle and thus from climatic variation. They are also ideal in an emergency like an earthquake, if water from shallower aquifers has become contaminated or depleted. This ‘fossil’ water is not replenished, however, so once it is gone, it is gone forever. Yet the Nigerian city of Lagos relies permanently on deep boreholes (800 m+) to compensate for its chronic water supply problems.

There are few specific regulations governing water in deep-seated aquifers, as van der Gun et al. (2012) recall in one of the thematic papers written for the Groundwater Governance Project. In some countries, mining laws even supersede water law beyond a certain depth.

Even deep-seated aquifers can be affected by pollution or depleted. In the 1930s, abandoned oil and gas wells in Kansas (USA) were found to be responsible for the salinization of aquifers. Deep-seated aquifers may also be contaminated by drilling fluids, the infiltration of surface disposal or reinjected fluids.

‘Oil and gas wells are the second most wide-scale intrusion into the underground space after water wells,’ observe van der Gun et al. ‘By the second half of the 20th century, major oil companies had built up a very questionable legacy of bad practices in many oil and gas provinces. These companies are adept at evading any subsequent penalties arising from cavalier practices, as seen in the Niger Delta, where the environmental damage places it in the world’s “top ten” of worst contamination events.’
The authors recommend that countries with weaker legislation or enforcement capabilities review their oil and gas licensing agreements to make sure these include ample internationally recognized indemnities to cover all potential resource and environmental degradation. As the oil and gas companies will resist such a move, the authors suggest that either the WTO or another relevant UN agency could design and implement this insurance cover on behalf of oil and gas exporting countries.

NEW FRONTIERS, NEW RISKS

Several new frontiers in electricity generation involve drilling to reach unconventional sources of energy. These include oil (or tar) sands, an industry pioneered by the Canadian State of Alberta, and shale oil and gas. All three resources are extracted using techniques that consume a lot of water and … energy.

According to Alberta Energy,\(^4\) 80% of the state’s known oil sand reserves lie more than 75 m beneath the surface, too deep for open-pit mining. Various techniques are used to extract these deep-seated resources, which represented 49% of total oil sand extraction in 2011. There is concern that aquifers may be contaminated both by drilling and by surface pollution, which can percolate through geological layers. Open-pit mining requires 8–10 barrels of water for every

\(^4\) See: www.energy.alberta.ca/OilSands/791.asp
barrel of oil produced. Even though much of this water is recycled, it still ends up mixed with sand and chemicals as slurry in artificial lakes known as tailing ponds.

**Preserving the Pacific’s fragile underground lifelines**

For the low-lying atoll nations of the Pacific, securing safe and sufficient fresh water is a constant challenge. Unreliable rainfall patterns and the absence of lakes or rivers mean that many atoll communities rely almost exclusively on small and fragile lenses of freshwater that ‘float’ on the underlying seawater.

Both the quality and quantity of this groundwater are now threatened by population growth, urbanization and climate change. Groundwater is already suffering from saltwater intrusion as a corollary of rising sea levels. Rainfall is also becoming increasingly erratic, raising the spectre of periodic drought.

In the small island state of Kiribati, population densities are among the highest in the world, yet the population is growing at a rapid rate of 3.87% per annum. This is having a profound effect on groundwater.

Kiribati is a collection of 32 low-lying atolls spread across 3.5 million km$^2$ of ocean.

Nearly half of the small island state’s 103 000 citizens live on the main island of South Tarawa. Here, widespread contamination of groundwater by nitrates and bacteria, compounded by saltwater intrusion, has left residents dependent on a piped water supply that is available for only two hours three times a week. The government is now contemplating expensive alternatives to groundwater like desalination technologies.

Necessity being the mother of invention, this dire predicament has spawned a number of innovative approaches. The recent success of ecosanitation, or composting toilets, in Tuvalu is being shared with 11 other Pacific countries. Pisi Seleganiu, Project Manager of Tuvalu’s Integrated Water Resources Management Demonstration Project, is actively assisting the Marshall Islands, for instance, in building and testing composting toilets on Majuro Atoll. This project is funded by GEF and coordinated by the Secretariat of the Pacific Community’s Applied Geoscience and Technology Division (SOPAC).

SOPAC is also coordinating national training workshops in ecosanitation in Kiribati and elsewhere which bring together all the relevant ministries – those for agriculture, land development, public works, environment, water, health, etc – with relevant NGOs.

Source: Dave Hebblethwaite, SOPAC
Likewise, the technique used to extract shale oil and gas, hydraulic fracturing of the rock using pressurized fluids, ‘has become a contentious environmental and health issue,’ state van der Gun et al., ‘with France banning the practice and a moratorium in place in the State of New South Wales (Australia), Quebec (Canada) and some states of the USA. Concerns […] include the contamination of groundwater, risks to air quality, the migration of gases and hydraulic fracturing chemicals to the surface and the potential mishandling of waste.’

Another new frontier is ‘supercritical water’, a form of geothermal energy currently being experimented in Iceland, where three wells have been drilled to a depth of 4–5 km. Above 374°C and 221 bar pressure, the distinction between liquid and vapour disappears as water enters a supercritical phase. This water is brought to the surface as superheated steam. Although supercritical water is renewable – the water is reinjected into the aquifer – its extraction is energy-intensive and costly.

Geologists are also exploring carbon capture and storage. It is planned to store carbon dioxide (CO$_2$) in unused gas and oil reservoirs and other underground repositories to reduce carbon emissions to the atmosphere. As CO$_2$ tends to become liquid or supercritical beneath 800 m, it will most likely be stored beyond this depth. One concern is that this liquid CO$_2$ could then leak into aquifers.

**FEW URBAN EXPERIMENTS IN COLLECTIVE GOVERNANCE**

Most experiments in groundwater governance are taking place in rural settings, where agricultural use dominates. In India, for example, one village council faced with overpumping took things into its own hands, with pleasing results (see box).
A village council takes charge

Overpumping of groundwater is a familiar problem to both rural and urban India, with aquifers being depleted in the hard rock terrain of peninsular India, the coastal regions and in the sedimentary aquifers of the Ganges valley.

The village of Hivre Bazar lies in the elevated, drought-prone Deccan Traps area of Maharashtra State. The 1200 villagers grow staple crops primarily for home consumption. In good years, almost 60% of the land can be irrigated but, in times of drought, wheat and summer crops have to be radically reduced. In the early 1990s, farmers struggled to feed their families and cattle without leaving the village periodically in search for paid work.

Under the leadership of an informed and charismatic chief, the Village Council adopted a comprehensive five-year plan in 1994 to improve groundwater management, as part of the Maharashtra Ideal Village Social Development Scheme.

Most importantly, village-level crop-water budgeting was introduced in 2002. In dry years, villagers are asked to reduce their proposed irrigated area and to give preference to low-water demand crops, with mutual surveillance usually being enough to achieve compliance. Sugarcane cultivation has been banned, owing to its high water consumption.

The Village Council also prohibited the use of borewells for agricultural irrigation. This incited farmers to maximize benefits from groundwater rather than competing with one another to dig deeper into the aquifer. Livestock grazing was also banned from some areas to favour reforestation.

This proactive approach to groundwater management has resulted in a marked contrast between Hivre Bazar and most of the surrounding villages.

Source: Héctor Garduño et al. (2011) India Groundwater Governance Case Study. World Bank

There is little evidence of collective approaches to aquifer management among urban users, even though groundwater dependency can be higher in peri-urban and urban areas than in rural areas. This is all the more problematic in that the urban population is slated to nearly double to 6.3 billion by 2050, up from 3.4 billion in 2009. High population growth in many of the world’s cities is already creating a shortage of freshwater that can be an acute source of tension. For instance, high tariffs or an inefficient water distribution system can incite urban dwellers to bore private wells.
This is what happened in Aurangabad City. Located in the elevated, drought-prone interior of Maharashtra State (India), the city has very limited groundwater. In the past 20 years, its population has grown rapidly to 1.1 million. Many inhabitants have bored private wells to ensure a reliable water supply. Since 2004, the Aurangabad Municipal Corporation has been considering increasing the quantity of water it imports from a reservoir situated 45 km distant. The scheme would necessitate an initial investment of US$80 million and generate high recurrent costs. The municipality has been trying to introduce volumetric charging (household meters), in order to ensure cost recovery and manage demand, but the proposal has met with public resistance. One solution might be for the municipality and relevant state government departments and agencies to form a standing committee, in order to devise a policy that would regulate the exponential rise in the number of private bore wells.

In Fortaleza in northeastern Brazil, one of Latin America’s fastest-growing cities, the supply of surface water by the Companhia de Agua e Esgoto do Ceará tends to be unreliable during periods of peak demand and drought. This has prompted 40–60% of the population to supplement its water supply with private wells. In 2003, there were almost 10 000 documented wells in Fortaleza, a six-fold increase over 1980. Over 70% of these wells are polluted with raw sewage or seawater.

One consequence of overmining an aquifer is subsidence (see box). Confronted with severe subsidence of 7.5 m in the city centre which played havoc with infrastructure, building foundations and sewerage systems, Mexico City decided to relocate its wells to the suburbs. Subsidence in the city centre subsequently dropped to about 3 cm per year … but the suburbs were then found to be sinking by 45–60 cm a year!5

5 See A World of Science: http://unesdoc.unesco.org/images/0013/001399/139966e.pdf
The day Bangkok began sinking

Greater Bangkok is underlain by a very productive aquifer system. Widespread exploitation of this groundwater commenced in the 1950s, leading to land subsidence of over 60 cm in the central city by the mid-1980s. The subsidence caused substantial damage to urban infrastructure and exposed the coastal city to a high risk of flooding during tidal surges. To compound matters, seawater intrusion threatened the quality of groundwater.

The public water authority progressively closed its pumping wells from 1985 onwards. However, the rising cost of tariffs for those connected to the mains water supply induced domestic, commercial and industrial users to drill private wells.

Confronted with a deteriorating environment, the government redoubled its efforts to control pumping by defining ‘critical areas’ where water well drilling was banned, adopted the power to seal water wells in areas connected to the mains and licensed and charged for groundwater according to metered (or estimated) abstraction rates. Initially, pricing provided little incentive to reduce pumping but at least it established an administrative framework and useful database. Subsequently, charges were raised and structured to ensure that the greatest financial burden was borne by industrial and commercial users in critical areas. Public awareness campaigns were introduced as the well-sealing programme was aggressively pursued.

Slowly, the situation was brought under control. By 2008, there were just over 4 000 licensed water wells in Greater Bangkok providing about 15% of the total water supply. Licenses are required for all wells more than 15 m deep. About 58% of the current licensed production is for industrial use. Many of the largest industrial water-users have been driven out of Greater Bangkok by the steep water charges.

Conflicts arose in some districts when an extension of the mains pushed up the cost of water. The dispute was resolved by allowing people to continue using their wells conjunctively for the duration of their current license and to retain their wells as a back-up supply for 15 years, provided they were adequately metered and open to inspection.

One groundwater management aspect which remains outstanding concerns groundwater pollution control in the recharge area to the north of Bangkok. Whereas the local regulatory agency has responsibility for identifying areas of higher vulnerability that lie within the capture zones of municipal wells, it has no jurisdiction over activities that are potentially polluting, such as the storage and handling of industrial chemicals, effluent discharge to the ground and agricultural practices. This urban–rural ‘co-management’ issue clearly needs resolving.


Food market in central Bangkok. Overpumping of groundwater caused subsidence in the 1980s which the authorities managed to bring under control by closing a number of wells. ©Susan Schneegans/UNESCO
TENSIONS AT THE PERIPHERY

Peri-urban areas and the urban–rural interface are becoming the theatre of a new form of simmering conflict. Among urban, domestic and agricultural users, an unhealthy competition is developing for the same resource.

Howard (2011) explores this theme in a thematic paper written for the Groundwater Governance Project. He explains that most groundwater-dependent cities are ultimately reliant on external aquifers over which they may have little, if any, jurisdiction or influence. The cities worry that farmers in peri-urban and rural areas will overmine the aquifer or pollute it with chemical fertilizers, pesticides, herbicides or wastewater. Attempts by cities to protect their drinking water at the periphery are often impeded by the fragmented nature of the administration, with regulations governing land use being disconnected from pollution control or from water use.

Howard observes that rural communities likewise feel at a disadvantage but for different reasons. Either they cannot compete financially with their urban neighbours or they are unable to influence water allocation owing to being less represented in positions of power, such as political parties and lobby groups. Farmers also worry about their groundwater being contaminated by urban runoff.

They agree with their urban neighbours on one point, though; it is very difficult to regulate when there are so many actors involved. NGOs, foreign government assistance programmes and private companies often act independently and work with different government ministries when implementing their respective agendas. The lack of co-ordination prevents responsible resource management (see box).
Growing pains in Zhengzhou

Zhengzhou is a rapidly growing city of 8.6 million. It is located in the lower reaches of the Yellow River in water-scarce northern China. Some 39% of the population lives within the city limits and 61% in the surrounding rural area.

Groundwater represents about 70% of Zhengzhou’s water supply, with just over half being used for agriculture. Industry is the next biggest user, at 31%.

Between 1990 and 2000, the number of tube wells increased from 37,164 to 42,763, lowering the water table and causing a shift from shallow to deep tube wells. Most of the new deep tube wells were funded by the government or village collectives.

In the city, sources of pollution include wastewater from industry and domestic sewage, whereas, in rural areas, the problem stems from fertilizers, pesticides and wastewater from livestock. According to the Water Resources Bureau of Zhengzhou, 1.5 million farmers (38% of all farmers) lack access to safe drinking water from ground or surface sources.

In theory, many of these problems could be resolved by requiring that all water-resources management, including groundwater, fall under the Ministry of Water Resources and its provincial and local arms. The reality is that, like in most of the world, management is scattered among a multitude of agencies, many with overlapping responsibilities. Insufficient communication and, in some cases, competing interests have resulted in groundwater regulations and policies being ineffectively implemented, or even conflicting one another. For example, one agency in Zhengzhou was working to close urban tube wells while others were opening new ones!

A reasonable goal would be to build institutional frameworks under which ministries and agencies with differing mandates and goals could share information on the state of groundwater resources and the impact of use. This would generate at least partial coordination of policies for groundwater management. It has been suggested that the Water Resources Bureau of Zhengzhou could take the lead and serve as a focal point for communication and coordination within Zhengzhou.


ADDING ANOTHER LAYER OF COMPLEXITY

From the foregoing, it is obvious that governance of the world’s groundwater resources is still in its infancy. This is true at the local and national levels and even more so when it comes to transboundary aquifers, given the complexity of sharing groundwater across two or more borders.
To manage any aquifer efficiently, you need reliable data and information. Unfortunately, a decade ago, there was still very little knowledge of transboundary aquifers and certainly no regional or global estimations.

Farmers on the Deccan plateau measure rainfall at one of 190 rain gauge stations, within an FAO project which is teaching them how to manage their limited freshwater resources in a sustainable manner. ©FAO/Noah Seelam

To remedy the problem, UNESCO’s International Hydrological Programme (IHP) launched the International Shared Water Resources Management (ISARM) programme in 2001. ISARM was the first attempt to inventory all transboundary aquifers and establish criteria for the sustainable management of these systems. As its name suggests, ISARM brings together specialists not only in hydrogeology but also from the legal profession, economics, international relations and ecological sciences.

ISARM’s accomplishments include the compilation of regional inventories and the publication of the first Atlas of Transboundary Aquifers in 2009; the most recent update of the global map of transboundary aquifers, prepared in 2004, was released in 2012 (pictured). The ISARM inventory revealed that transboundary aquifer systems could extend over thousands of square kilometres and that the great majority were not directly connected to any international river basin.
In just over a decade, ISARM has mapped more than 400 transboundary aquifers. The first continent to be targeted was Africa, in 2002. This was followed by the Americas in 2003, Asia in 2005 and the Balkans in Southeast Europe in 2009. Each inventory took several years to complete and helped to strengthen the knowledge base in other regions. The experience gained in Africa of karst aquifer systems, for instance, proved extremely useful in designing the DIKTAS project for Southeast Europe (see box).

Having a common purpose can favour reconciliation

The Dinaric Karst Aquifer System (DIKTAS) in Southeast Europe is one of the largest in the world. Like many karst areas, permeable rocks make up much of the landscape and there is only a thin layer of soil, if any at all. Rainwater seeps through the rock, resulting in an almost total lack of rivers and lakes and making groundwater the primary source of freshwater.

Prior to the 1991–1995 war which split Yugoslavia into several autonomous states, tourism was the main economic activity on the coast, compared to agriculture and hydropower inland. Today, the region’s economic growth has been spurred, at least for some countries, by the opening of negotiations for accession to the European Union. Countries have enthusiastically embraced the European Framework Directive, which provides a framework for sustainable water management.

In 2009, UNESCO began carrying out a transboundary diagnostic analysis of the aquifer system to identify gaps in knowledge. This was part of the preparatory phase for the DIKTAS project, which assists Albania, Bosnia and Herzegovina, Croatia and Montenegro in particular in managing this precious resource. The project is funded by GEF, implemented by UNDP and executed by UNESCO.

In November 2010, the practical component of the four-year project got under way. Data were collected and a regional database compiled during this first phase. The project is now putting mechanisms in place for the regular exchange of this information and data, while fostering greater cooperation among the participating countries.

Experts are currently conducting an in-depth analysis of the characteristics of the Dinaric Karst Aquifer System and its boundaries. Solutions are also being explored to the problem of competing demands for groundwater, coupled with pollution in some areas.

There is no multicountry policy at present to regulate land use and development planning, even though the aquifer is highly vulnerable to contamination and the upstream dams have an impact on downstream users. Even at the national level, there is often insufficient coordination among ministries, such as those for water, the environment, tourism, agriculture, spatial planning, forestry and energy.

The project is advancing so well that it looks as if the creation of a subregional cooperative mechanism will go ahead as planned.

Source: UNESCO
COMING SOON: A LAW ON TRANSBOUNDARY AQUIFERS

Although groundwater represents 97% of available freshwater – the remainder being found in rivers and lakes – international law paid little attention to it until recently.

There are currently two global conventions on the use of transboundary water resources. The first is the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992), which includes transboundary groundwaters. It concerned only the countries of UNECE until February this year when it was opened to all UN Member States. The second is the UN Convention on the Law of Non-navigational Uses of International Watercourses (1997), which considers groundwater only when related to a surface water body; it has not yet entered into force.

Transboundary aquifers of the world (2012)

Source: www.isarm.org/publications/419

ISARM lifted a key obstacle to the development of an international law on transboundary aquifers specifically by establishing the first global inventory. In 2008, the UN General Assembly adopted Resolution 63/124, which includes, in annex, a set of draft articles prepared...
by the UN International Law Commission with the scientific and technical support of the UNESCO-IHP.

These draft articles include the core principles of international water law: equitable and reasonable utilization and the no-harm rule. They also include the general principle of international law, the obligation to cooperate, translated in a practical manner in the case of transboundary aquifers into the regular exchange of data. The draft articles then codify specific principles for the management of transboundary aquifers, such as their monitoring and protection, as well as for direct cooperation with developing states, or indirect cooperation through a competent international body like UNESCO.

The latest draft of the law is due to be discussed at the UN General Assembly in New York (USA) later this year. Whether or not the law is adopted in October, ISARM will continue encouraging governments to set up their own plans and commissions to manage shared aquifers jointly with their neighbours.

This is already the case in the Sahara (see box) and Latin America (see box), for instance, where countries collaborate in managing three of the largest deep-seated aquifers in the world. The Guarani Aquifer Agreement (2010) is even the first to ‘take[e] into account also Resolution 63/124 of the UN General Assembly on the Law of Transboundary Aquifers.’

Agreements can also be brokered at the local level. In the arid border regions of Chihuahua (Mexico) and Texas (USA), concerted efforts across the border to foster conservation, quality wastewater treatment and artificial recharge of the Hueco−Bolson aquifer have paid off. The aquifer is the sole source of water for Ciudad Juarez (Mexico) and accounts for 30% of the domestic water supply for the city of El Paso (USA). Pumping of the aquifer by El Paso peaked at a high of 98 700 km$^3$ in 1989 but had been halved by 2002.
Managing fossil water in the Sahara

Some 10 000 years ago, the barren Sahara was a lush savannah. When the rains that fed the region disappeared about 3 000 years ago, they left behind a precious legacy: 373 000 km$^3$ of ‘fossil water’ in the twin reservoirs of the Nubian Sandstone Aquifer System, which spans Chad, Egypt, Libya and Sudan.

A Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System was established between Egypt and Libya in 1989 to manage the aquifer system in a collegial fashion; it was formally launched in 1991, through the agreement on the Constitution of the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer Waters. Sudan joined in 1996 and Chad in 1999.

In 1991, Libya began piping the aquifer’s water across the country through the Great Man-Made River Project, the world’s largest civil engineering scheme. As this fossil water cannot be replenished, this move sparked controversy.

In 2000, Chad, Egypt, Libya and Sudan joined the Programme for the Development of a Regional Strategy for the Utilization of the Nubian Sandstone Aquifer System. Run by the Centre for Environmental Development of the Arab Region and Europe, the programme helped the countries to work together while giving the Joint Authority an active role.

In 2006, the IAEA launched a three-year study of the transboundary aquifer within the Nubian Project, together with UNDP, UNESCO and GEF. Specialists first prepared a Shared Aquifer Diagnostic Analysis of the priority issues and threats to the aquifer system. They then used sophisticated technology to fill the data gaps that were hindering strategic planning. A Strategic Action Programme followed, outlining the necessary legal, policy and institutional reforms needed to address the priority threats identified earlier by the project and their root causes.

The second-biggest aquifer system in the Sahara covers an area of about 1 million km$^2$ and is shared by Algeria (69%), Libya (23%) and Tunisia (8%). These three countries established a Consultative Mechanism for the Northwestern Sahara Aquifer System in 2002.

In the case of both aquifer systems, cooperation does not seem to have been perturbed by the regime change in Egypt, Libya and Tunisia during the Arab Spring of 2011.

Source: UNESCO/IAEA

A CHALLENGE WE CANNOT AFFORD TO IGNORE

As Alice Aureli, Senior Programme Specialist with the UNESCO-IHP, said at the Nairobi consultation last May, formulating good governance strategies for groundwater is a challenge we cannot afford to ignore. In the face of the unprecedented challenges that lie ahead,
not least of which involves nearly doubling food and energy production in the next 40 years while coping with climate change and embracing sustainable development, humanity’s very survival will depend upon how well we treat the lifeline beneath our feet.

Compiled by Susan Schneegans. Much of the information in this article comes from the website of the Groundwater Governance Project: www.groundwatergovernance.org

An aquifer of plenty

The Guarani Aquifer extends over 1.2 million km² and is thought to be the largest in Latin America. It is shared by Brazil (71%), Argentina (19.1%), Paraguay (6.1%) and Uruguay (3.8%).

People tend to associate Brazil with luxuriant vegetation and fast-flowing rivers but parts of the country are semi-arid, like the northeast. In these areas, nearly one-third of the total water supply comes from aquifers. Moreover, in the populous southern State of São Paulo, as much as 60% of urban centres are served by groundwater.

At the time it was launched in 2003, the Guarani Aquifer System Project was the first in Latin America to focus on transboundary aquifers and one of the first multicountry initiatives in groundwater to be undertaken worldwide. The project involved all four riparian countries and was funded by GEF. The World Bank implemented the project, whereas the Organisation of American States served as executing agency.

The quality of water in the Guarani Aquifer was found to be good, although some hot spots of pollution were detected in the recharge and extraction areas. It is still not known precisely what amount of water is drawn from the aquifer each year but scientists estimate that it could supply 300 litres of water per day to 720 million people.

The project first devised then implemented a common institutional framework for managing and preserving the aquifer. One achievement was the trust that developed among the four riparian countries, including through the sharing of information and data on the aquifer’s characteristics.

The Ministry of Foreign Affairs in each country proved to be a critical actor in negotiations over the aquifer’s management. The project also stimulated debate in the media and university sector. It clearly contributed to the success of the ISARM Americas Programme and has been hailed as a model for other countries to follow.

The project culminated in the adoption of the Guarani Aquifer Agreement on 2 August 2010. This umbrella agreement outlines general principles for cooperation among the four riparian countries and details plans for an institutional mechanism which would manage the aquifer within the Commission on the Río de la Plata.

Source: UNESCO

Rush hour at an underground station in São Paulo, one of the world’s biggest megacities. Across the state, 60% of urban centres are served by groundwater. Photo: Wikipedia
The African Journal of Chemical Education (AJCE) is a biannual online journal of the Federation of African Societies of Chemistry (FASC). The primary focus of the content of AJCE is chemistry education in Africa. It, however, addresses chemistry education issues from any part of the world that have relevance for Africa. The type of contents may include, but not limited to, the following:

**RESEARCH PAPERS** reporting the results of original research. It is a peer-reviewed submission that deals with chemistry education at any level (primary, secondary, undergraduate, and postgraduate) and can address a specific content area, describe a new pedagogy or teaching method, or provide results from an innovation or from a formal research project.

**SHORT NOTES** containing the results of a limited investigation or a shorter submission, generally containing updates or extensions of a topic that has already been published.

**REVIEWS** presenting a thorough documentation of subjects of current interest in chemical education.

**LABORATORY EXPERIMENTS AND DEMONSTRATIONS** describing a novel experiment/demonstration, including instructions for students and the instructor and information about safety and hazards.

**SCIENTIFIC THEORIES** describing the scientific, historical and philosophical foundations of theories and their implications to chemical education.

**ACTIVITIES** describing a hands-on activity that can be done in the classroom or laboratory and/or as a take home project.

**INDIGENOUS KNOWLEDGE AND CHEMISTRY IN AFRICA** as a special feature that addresses the relationship between indigenous knowledge and chemistry in Africa. It could be in the form of an article, a note, an activity, commentary, etc.

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