The Field of Chemistry Education Research
An Introduction

Savita Ladage
savital@hbcse.tifr.res.in

Outline

1. Chemistry as a domain and its learning difficulties

2. Genesis of Chemistry Education Research (CER)

2. Areas of Work done in the field of CER (UG level)

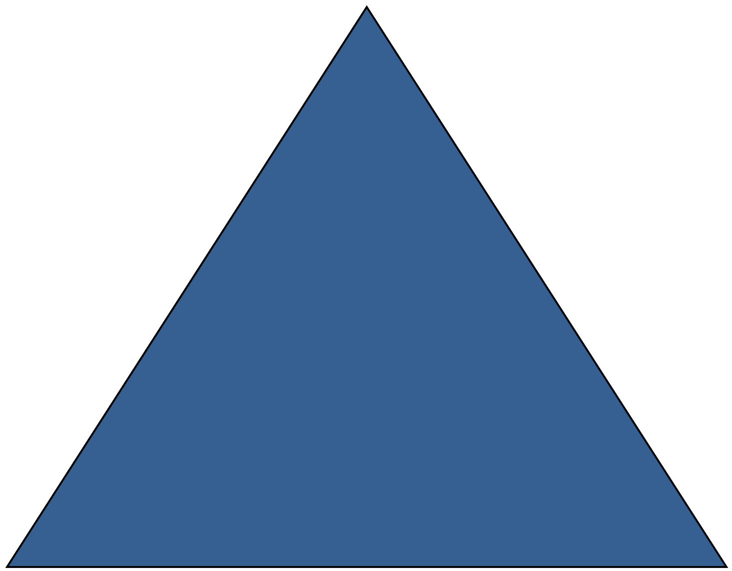
3. CER ideas and innovation in instructional methods at undergraduate level

3. Chemistry Education (CE) work at HBCSE

4. Indian Scenario and CERD work

Chemistry as a Domain and its Learning Difficulties

Chemistry as a Domain



Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*(7), 75-83.

Chemistry as a Domain

Chemistry : properties of substances and its transformations

Descriptive chemistry relies on qualitative aspects of matter
e.g. colour, smell, appearance (unlike physics)

Class concept is used extensively in chemistry

- e.g. acids, bases, aldehyde (as a functional group)
- helps in understanding likely properties of the substance
- helps to investigate and classify new substances

Chemistry as a Domain

Acids:

On one level- it refers to substance (physical entity) that exits in nature and at other level it is a concept (macro level- class of material / mental representation (microscopic)

The concept of acid has undergone changes over time (e.g. Arrhenius model, Brønsted-Lowry model, Lewis model – These models are based on empirical observations and are used today)

On other hand, you also have models as theoretical constructs: Ideal gas, Delocalization, Resonance

Chemistry as a Domain

Thinking with models: chemists visualize entities or processes- plan experimental work and support reasoning

In chemistry, models are used both at descriptive level and sub-micro level

Structure-property relationship

(concept of chemical bond is very crucial for chemistry)

e.g. Isomers

CH_3-CH_2-OH and CH_3-O-CH_3 (same formula- C_2H_6O) – difference in connectivity between atoms gives rise to huge difference in properties

Chemistry as a Domain

Model of Atom (central model in chemistry)

(school ----- Higher secondary -----Undergraduate)

Dalton to Quantum Mechanics (QM)

Post 1960s –computer revolution-

Wide range of spectroscopic techniques-for structure determinations in chemistry

QM model has become more central and is mathematical

Concepts/ Explanations: (orbitals) - neither completely true nor completely false - used widely in learning chemistry

Learning Difficulties

Abstractness of concepts – how to make them accessible to students?

Several plausible explanations exist for a given chemical system-

To develop a feel (judgement) to choose the appropriate explanation that dominates and is responsible for the observed behavior.

Experts have such (judgement) but the same is not true for students : Developing a feel for judgement is important in learning chemistry

Genesis of Chemistry Education Research (CER)

Genesis: Chemistry Education Research (CER)

Around 1960s- Interesting developments: in Psychology

Piaget

Ausubel

Vygotsky

Photos

http://2day.sweetsearch.com/jean-piaget-developmental-psychologist/

https://www.facebook.com/David-Paul-Ausubel-410702126417395/

https://en.wikipedia.org/wiki/Lev_Vygotsky

Chemistry : Major efforts to develop new curricula

e.g. Nuffield (UK), Chemical Bond Approach (USA), CHEM Study (USA)

Modern theories of bonding (Quantum Mechanics based)-

became central to the curricula

Genesis CER

Key ideas-learning

Ausubel

Prior experiences/knowledge plays a crucial role in learning (anchor learning on prior knowledge/ experiences)

Piaget

Cognitive disequilibrium – key for advancing Learning

Vygotsky

Socially mediated environment enhances learning - co-operative/collaborative environment is important for learning

CER/Genesis

Curriculum projects (1960s)

Interactions among content (chemistry) people, cognitive psychologists and teachers

1970s :

Introduction of new textbooks- situation with respect to learning in classroom did not change much

The serious need for systematic research in CER was felt around this time (like PER)

CER/Genesis

CER: Discipline Based Research (DBR)

Focus

Systematic investigation of learning chemistry- grounded in theories of learning

Informed by

- History of development of concepts in chemistry
- Practices in chemistry
- Priorities of chemistry as a discipline

One needs to understand the ways by which knowledge of chemistry concepts is constructed by learners

Work (Research) done in Chemistry Education

CER/Areas

Cooper & Stowe (2018): reviews the growth of CER from genesis till date- captures various areas of research, kind of questions investigated by CER studies in these areas

Teo *et al.* (2014): reviewed 650 papers (2004 -2013)

Singer, S.R. *et al*. (2012): Discipline Based Education Research (DBER) report - Understanding and improving learning in undergraduate science and engineering- compares DBER in physics, chemistry, biology, astronomy and engineering

Towns and Kraft (2011): work done at undergraduate level reviewed 379 papers (2000 -2010)

CER/Areas

General facts (Teo *et al.*- 2014)

Major Work done at University level 353 papers in higher education, 163 pre-university level

Location of the studies

North/Central America (48%), Europe (35%), Asia (11%),

Oceania (4%), Africa (2%)- global

Methodology: both qualitative and quantitative

Less explored areas

Nature of chemistry, and the cultural, social, gender, historical, philosophical aspects of chemistry education

Areas of Research in CER

1. Conceptual understanding/Misconceptions
2. Learning in chemistry laboratory
3. Representations in chemistry
4. Problem solving
5. Pedagogy

1. Conceptual Understanding/Misconceptions

Most researched area (since inception of CER)

Emphasis on students' conceptions about individual topics in chemistry (Cataloguing/ identifying robust ones)
e.g. Atomic structure, thermodynamics, kinetics, equilibrium, chemical bonding, stereochemistry Lewis structure

Development of Concept Inventories (CIs)
Multiple choice format, useful in large classes and across range of students
e.g. General chemistry, thermodynamics, bonding, intermolecular forces, equilibrium, acids and bases

1. Conceptual Understanding/Misconceptions

Misconceptions: few examples

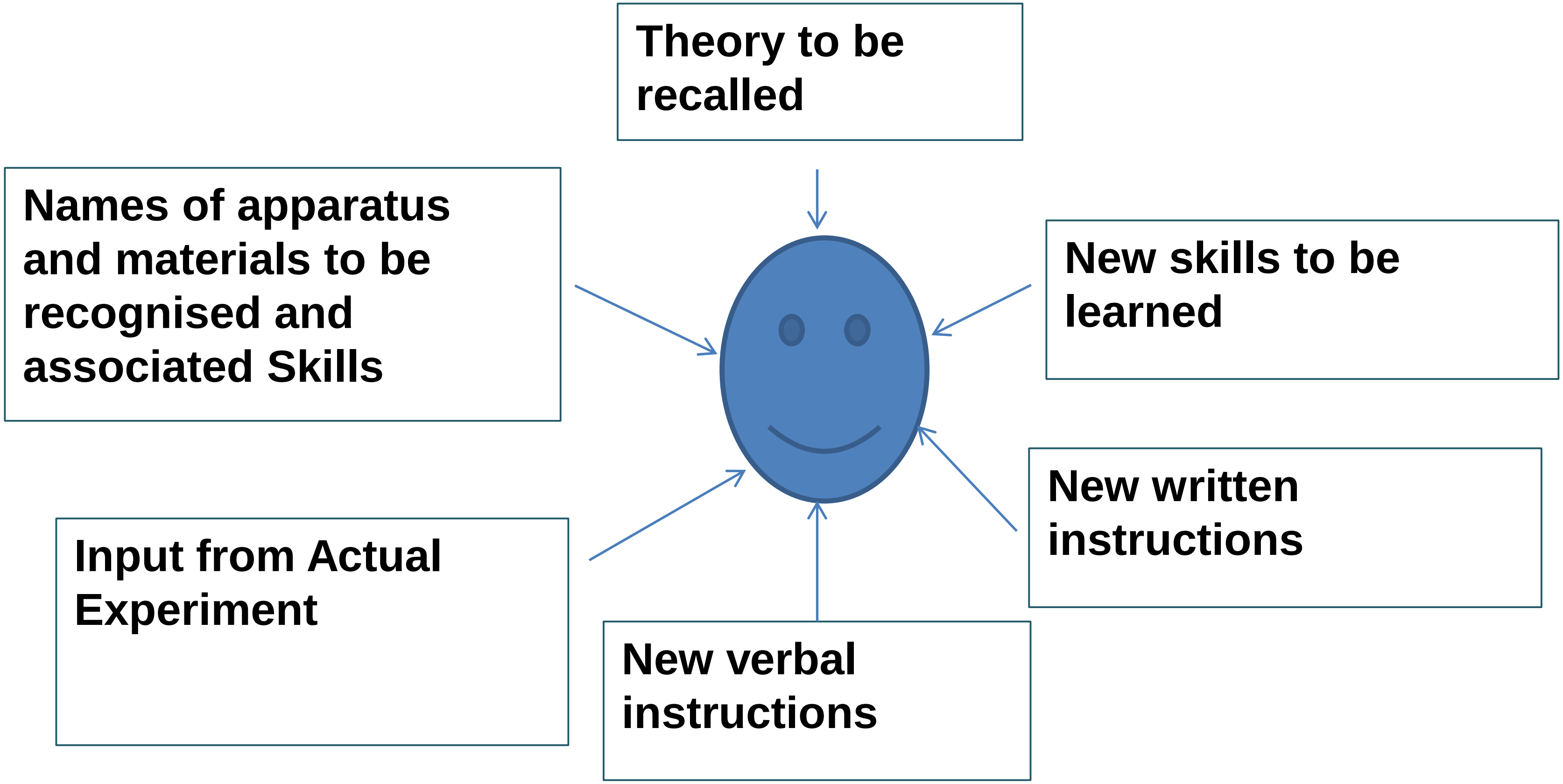
- Equal sharing of the electron pair occurs in all covalent bonds ($H_{2,}$ HCl)
- Reaction that proceeds more rapidly also goes to completion
- Exothermic reactions are always spontaneous
- No reaction takes place at equilibrium
- Reaction of acid and base will always give neutral solution (H^+ and OH^- cancel each other)
- Resonance structures are in equilibrium with one another and eventually stable structure is obtained

1. Conceptual Understanding/Misconceptions

To understand thinking of learner the questions can/needs to be of following types-

- Justify a choice (after selection of answer for *mcq* question)
- Explain the wrong answer
- Explain why something happens
- Explain how something happens
- Predict what happens next

2. Learning in Chemistry Laboratory



Role of the laboratory courses in chemistry education
What learning is happening in existing laboratory courses ?

Chemistry Laboratory

Shift laboratory practices towards inquiry based

- Expository lab: concept to data (deductive logic) inform-verify (Lab)- practice (Traditional)
- Inquiry based lab: data to concept (inductive logic) explore (Lab)- invent a concept- apply

Inquiry based approaches- guided inquiry, open inquiry

problem based learning (with interesting context)

Abraham, M. (2011). What can be learned from laboratory activities? Revisiting 32 years of research. *Journal of Chemical Education*, 88, 1020- 1025

Chemistry Laboratory

A rubric to characterize inquiry in the undergraduate laboratory.

Characteristic	Level 0: Confirmation	Level ½: Structured inquiry	Level 1: Guided inquiry	Level 2: Open inquiry	Level 3: Authentic inquiry
Problem/Question	Provided	Provided	Provided	Provided	Not provided
Theory/Background	Provided	Provided	Provided	Provided	Not provided
Procedures/Design	Provided	Provided	Provided	Not provided	Not provided
Results analysis	Provided	Provided	Not provided	Not provided	Not provided
Results communication	Provided	Not provided	Not provided	Not provided	Not provided
Conclusions	Provided	Not provided	Not provided	Not provided	Not provided

More structure ⟵⟶ **Less structure**

Close --Open
(problems, ways or means and answers)

Buck et al. (2008), Characterising levesl of inquiry in the Undergraduate laboratory, *J. Coll. Sci. Teach.*, 38 (1), 52-58

Open ended task

The ethylene glycol content of commercial antifreeze samples can be determined by an oxidation-reduction titration. Any number of other techniques can also be applied to this analysis. Devise two procedures, one of which involves a redox titration, and "test" them on synthetic samples of ethylene glycol. Then apply each method to the determination of ethylene glycol content of three different commercial antifreezes. Compare the two methods critically.

Wehry E. L. (1970) ."Open-Ended" Experiments for Undergraduate Analytical Chemistry, Journal of chemical *education* , 47(12), 843-844.

UG (and PG) Lab courses

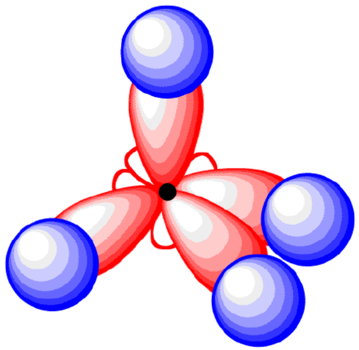
Develop students as Independent investigators and critical thinkers

Unless the opportunities are generated to develop the competencies needed, how students can make such meaningful successful transitions?

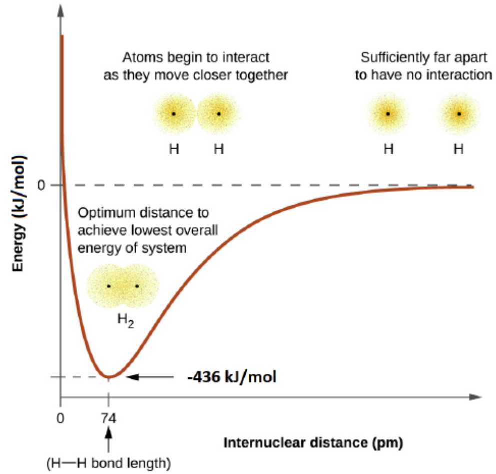
Students need to transit from

Well defined close situations (level zero experiments) to ill defined situation (experiment towards level 3, closer to real situation based problems or research problems or) with gradual transition

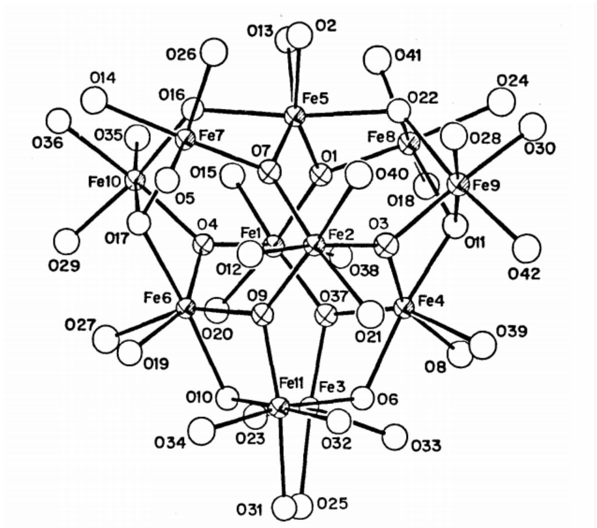
3. Representations in chemistry



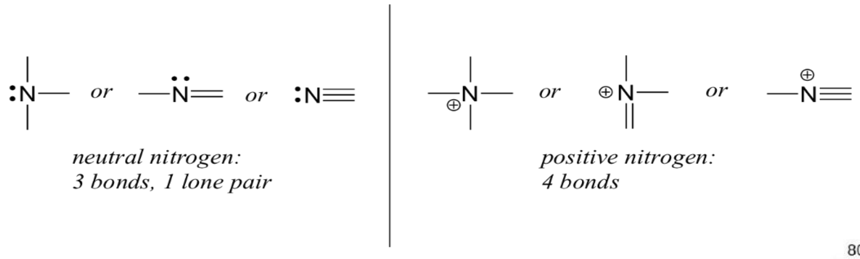
6

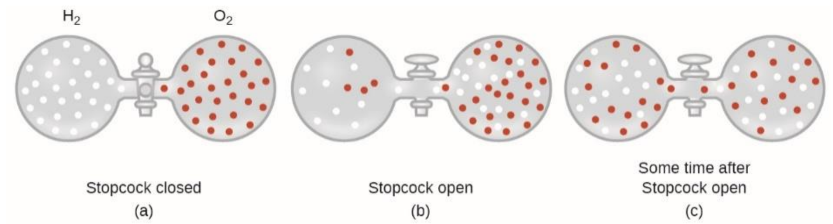


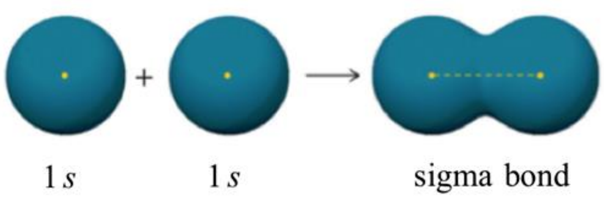
n=PVRT

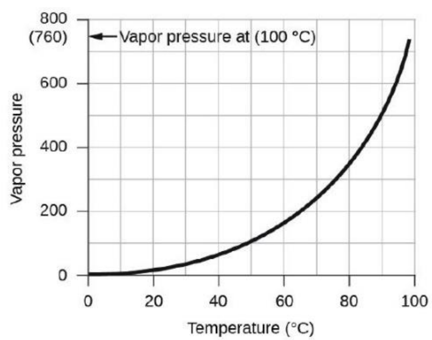


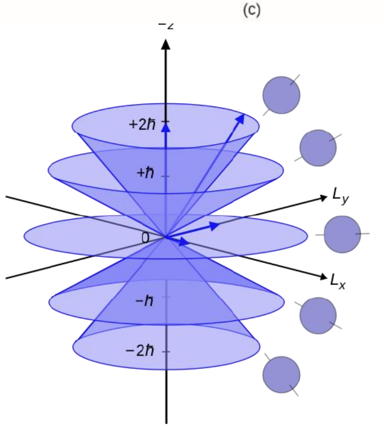
$2Ga(s)+6HCl(aq)\longrightarrow 2GaCl_3(aq)+3H_2(g)$











All images -https://chem.libretexts.org/Bookshelves

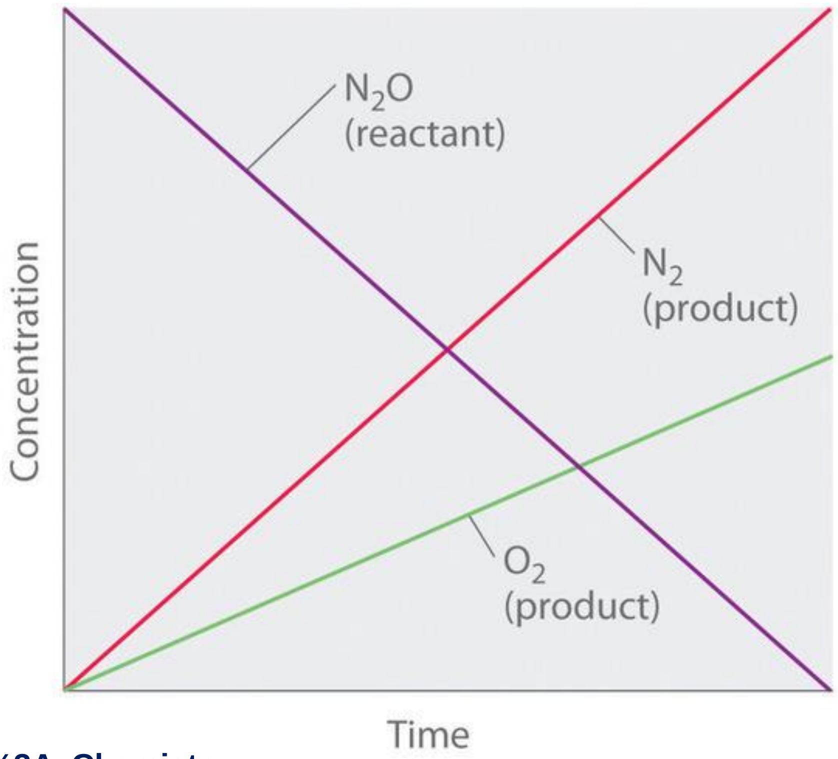
Representations

Representational competency: Translating between alternative representations that indicate the same set of relationship - video, graphs, animations, equations and verbal descriptions

Nitrous oxide (g) → nitrogen(g) + Oxygen(g)

$2N_2O(g) \rightarrow 2N_2(g) + O_2(g)$

Rate $= -1/2(\Delta[N_2O]/\Delta t)$
$= 1/2(\Delta[N_2]/\Delta t) = \Delta[O_2]/\Delta t = k[N_2O]^0$



https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/14%3A_Chemical_Kinetics/14.04%3A_The_Change_of_Concentration_with_Time_(Integrated_Rate_Laws)

4. Problem solving

Type of problems in chemistry

Numerical, Writing equations, drawing structures, completing reaction sequence/mechanisms etc.

What is

- Whether situations presented as part of these problems are familiar to students? (till end of UG)

- In true sense, whether such examples – can be termed as Problems(exercise ?

4. Problem solving

Studies focus on

Expert-novice comparisons, characteristics of successful problem solvers, complex problems and performance (load on working memory), performance on ill-defined (real)/open ended problems

What constitutes a problem?: Disagreement in CER

Problem solving research is a muddy area

Ill-defined problems (real world)/ open ended problems (Interactive Multimedia Exercises (IMMEX)- web platform after five attempts- student settles on a strategy even though it is not successful)

Cooper, M. M., Sandi-Urena, S. & Stevens, R. (2008). Reliable multi method assessment of metacognition use in chemistry problem solving. *The Royal Society of Chemistry*, 9, 18-24.

5.Pedagogy

Instructional strategies that are based on socially mediated forms of learning are more effective

Process Oriented Guided Inquiry learning (POGIL): based on learning cycle approach (explore- build-apply) (www. pogil.org)

CER ideas and innovation in instructional methods at Undergraduate level

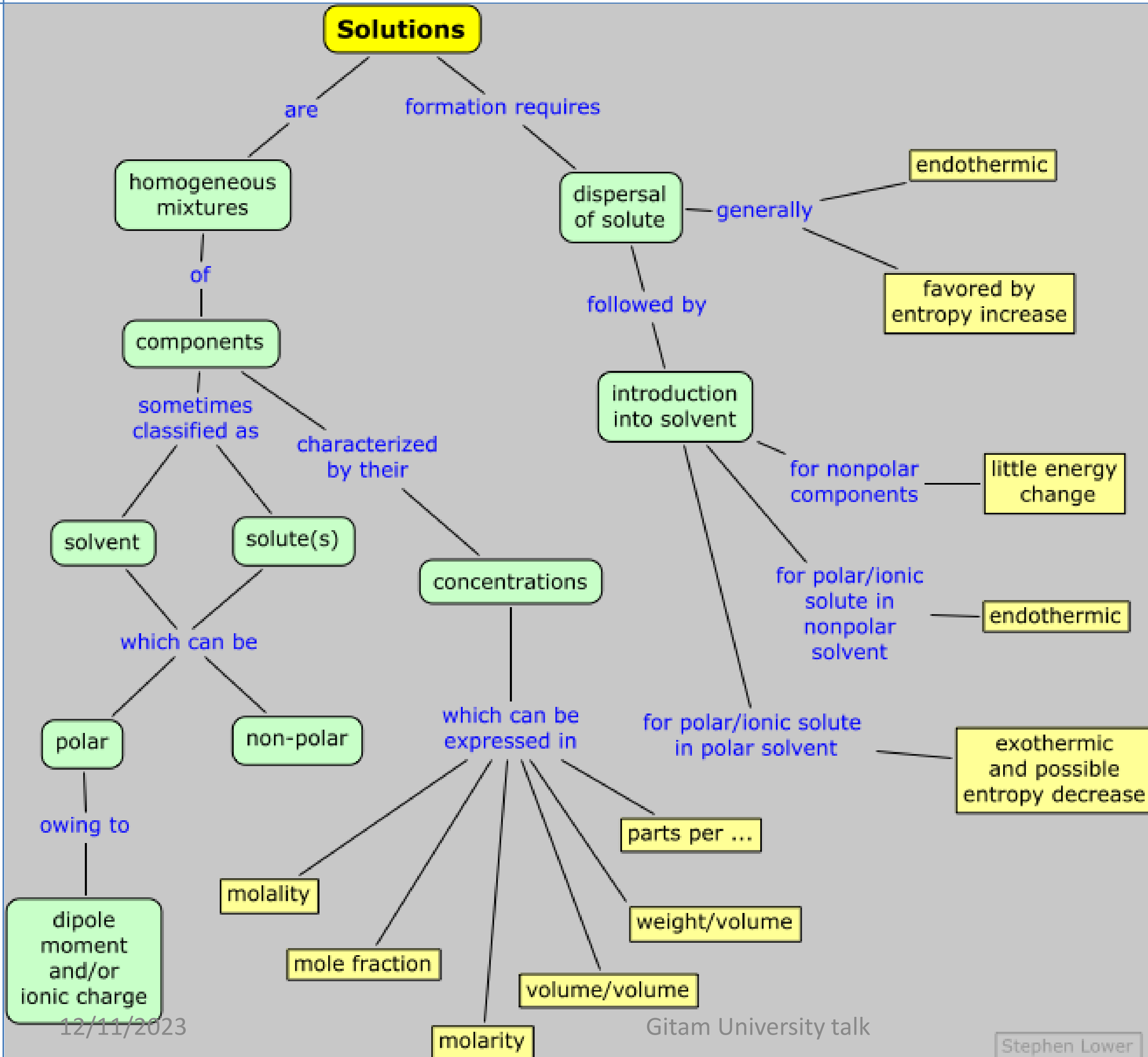
Example of knowledge organization tool

Concept maps- graphical representation

- Organization of concepts
- Most generalized concept at top
- Then specific concepts
- appropriate linkages needs to provided as connectors

Can be used as assessment tools-(*A priori* and *post facto*)

Example of Concept map



http://www.chem1.com/acad/webtext/solut/solut-1.html

Assessment –Example- how to frame questions

Dimethyl ether and ethanol have the same molecular formula. One of these compounds is liquid at room temperature and other is gas.

Draw Lewis structure for each compound. Use the drawn structures to determine which is liquid at room temperature. Provide molecular level explanation for your answer that should include discussion about interactions and energy changes involved.

Cooper and Stowe(2018): Chemistry Education Research- From personal empiricism to evidence, theory and informed practice, *Chemical Reviews*, 118,6053-6087.

CER ideas and innovation in instructional methods

Shift towards Active learning

Lectures

e.g. Interactive Lecture Demonstration, flipped classroom, Just-in-Time teaching, use of clickers, Introduction of pre-lecture activities

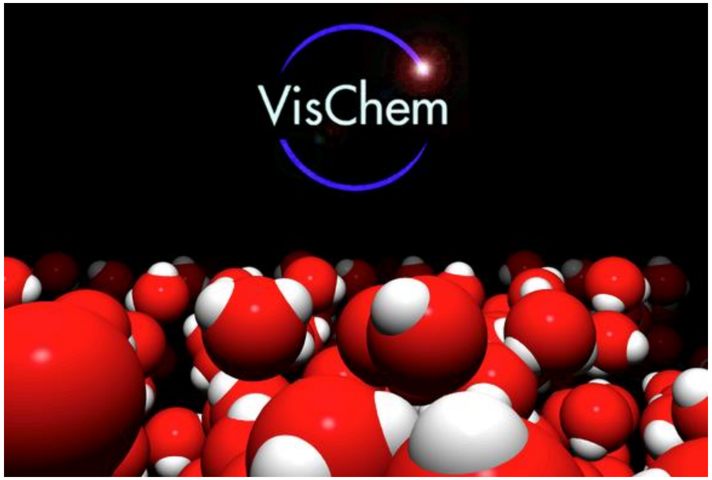
Chemistry laboratory

e.g. Pre-/post-laboratory activities (load on working memory), mini-projects, multi week projects

Problem based learning (real or open ended problems)

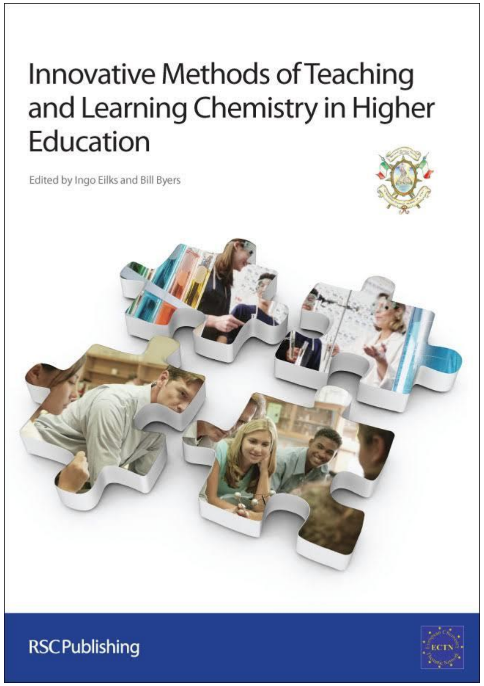
CER ideas and innovation in instructional methods

Multi-media support: Multiple representations- for better conceptualization of sub-micro aspects (http://www.vischem.com.au/)

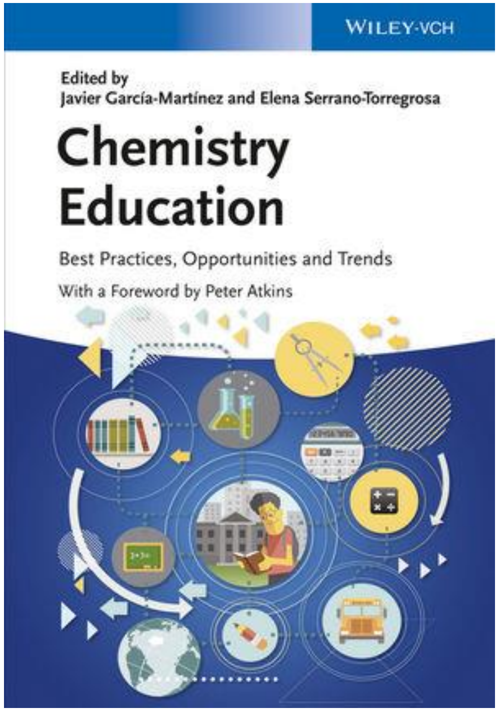


- PhET simulations
- Laboratory techniques (videos)
- Functioning of advanced instruments (simulations)
- Virtual laboratories
- lecture course material / supplementary material
- Assessment: online tests/ assignments

CER ideas and innovation in instructional methods



Working group was set to look into Innovative Methods in University Chemistry Teaching European Chemistry Thematic network (ECTN) 2006, the book is published in year 2009



Images
http://pubs.rsc.org/en/content/ebook/9781847559586#!divbookcontent

https://onlinelibrary.wiley.com/doi/epdf/10.1002/9783527679300.ch24

CER work at HBCSE

CE work/HBCSE

Capacity building programmes for chemistry teachers

Chemistry Olympiad - Exposure camps

Chemistry Teachers teaching at higher secondary

Thrust areas

- Experiments (hands-on) – enhancing understanding
- Introduction to context based questions

CE work/HBCSE

NIUS-Teacher Development camps

How do you generate learning opportunities in the existing chemistry laboratory ?

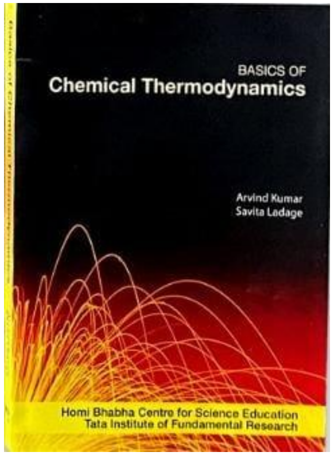
Can we write experiments differently?

Developing new experiments for undergraduate chemistry (new content)

Instructional material (physical chemistry)

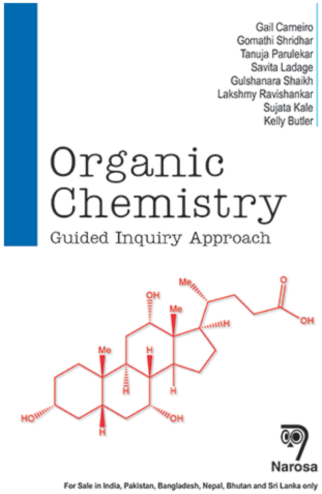
Chemical thermodynamics

https://nius.hbcse.tifr.res.in/subjects/chemistry/books-instructional-material/basics-of-chemical-thermodynamics/



Inquiry approach based Instructional Material

Narosa publications- *Organic chemistry: a guided inquiry Approach*- collaboration among HBCSE and teachers from colleges of Mumbai, Pune

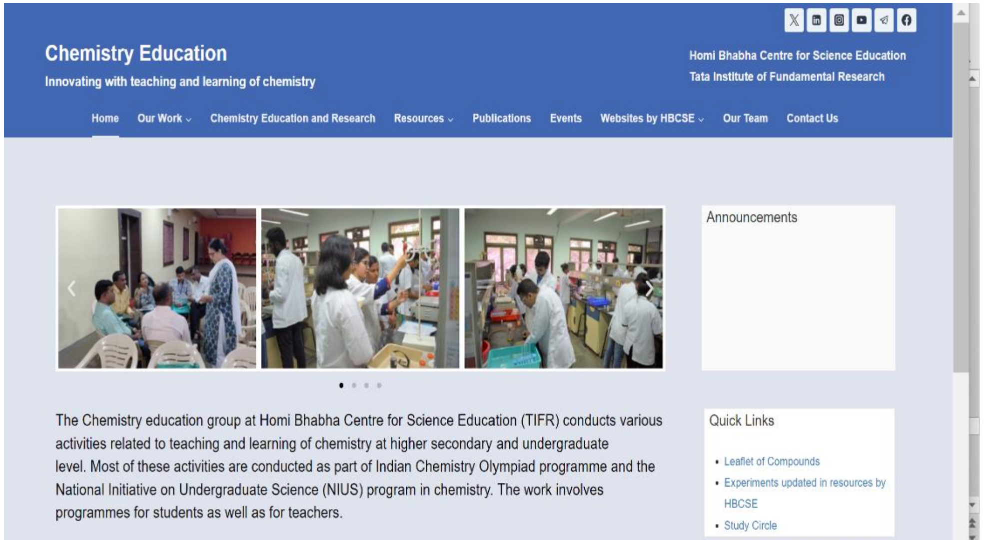


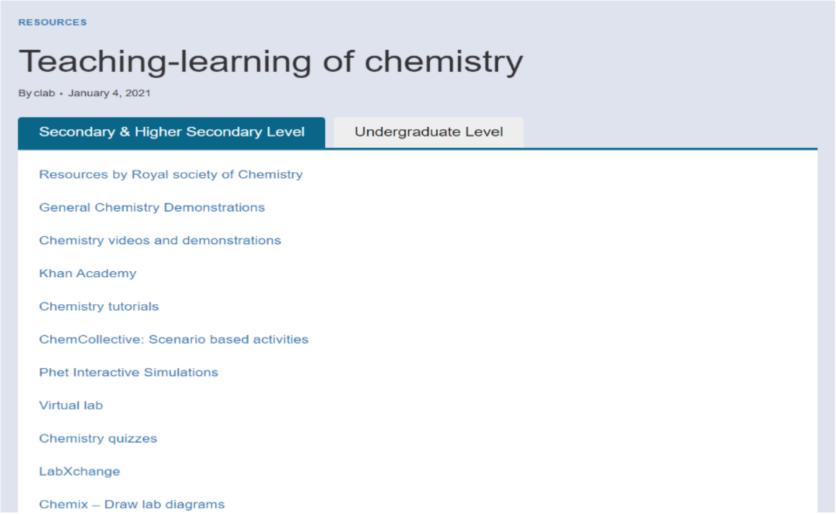
Book (in print)

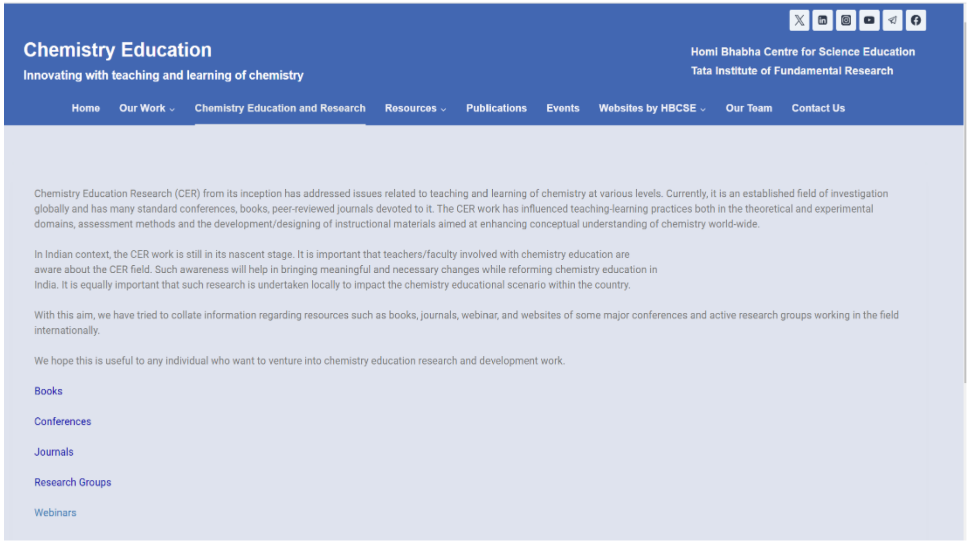
Lab experiments with pre-lab and post lab approach collaboration among HBCSE and teachers from colleges of Mumbai, Pune

CE work/HBCSE

https://chem.hbcse.tifr.res.in/







Current scenario in India and CERD (Research and Development)

Chemistry Education: Indian Scenario

Launching of several new institutions offering integrated B.S-M.S. programmes in sciences (along with new IITs)

e.g. Indian Institutes of Science Education and Research (IISERs), National Institute of Science Education and Research (NISER, Orissa), Centre for Excellence in Basic Sciences (CBS, Mumbai)

Launching of exchange programmes with universities abroad

State Colleges: becoming autonomous

NEP 2020- new changes are being initiated (w.r.t. teaching-learning)

What changed ?

- Different curricular models are available within India
- Excellent laboratory facilities (experimental)
- Autonomy to plan curricula, execution, assessments
- Sizable young population has entered in teaching of chemistry
- Realisation for teacher professional development (with emphasis on pedagogical dimension in higher education, e.g PMMMNMTT scheme)
- Use of ICT (including assessment) and E-resources (higher education)

Indian Scenario

Teacher professional development with emphasis on pedagogy have been initiated (and is important with content dimension)

It is important to bring awareness of CER and D work in Indian context and venture into such activities

Such a step will give evidence about what works and fails in our own systems and will provide basis for required reforms
Innovations for chemistry education at UG level (need of time)

(Quote from Foreword – Peter Atkins, page XXII)

"Concepts in chemistry at first sight are abstract, its arguments are intricate, its formulations sometimes mathematical and its applications spanning widely between horizon of physics and Biology. This perfect storm of aspects can be overwhelming and unless handled with utmost care and professional judgment, results in confusion and disaffection. The responsibility of educators is to calm this storm."

Garcia-Martinez,J, & Serrano-Torregrosa, E.(Eds.) (2015), *Chemistry Education: Best practices, Opportunities and Trends.* Wiley VCH: Weinheim, Germany.

References

- Cooper and Stowe(2018): Chemistry Education Research- From personal empiricism to evidence, theory and informed practice, *Chemical Reviews*, 118,6053-6087.

- Teo, T. W., Goh, M. T. & Yeo, L. W. (2014). Chemistry education research trends: 2004-2013. *Chemical Education Research and Practice*, 15, 470-487.

- Towns, M. H. & Kraft, A. (2011). Review and synthesis of research in Chemical Education from 2000-2010. A white paper for the National Academies National Research Council Board of Science Education, Committee on Status, Contributions, and Future Directions of Discipline Based Education Research.

- Singer, S. R., Nielsen, N. R. & Schweingruber, H. A., (Eds.) *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. The National Academies Press: Washington, DC, 2012.

All questions are welcomed!!!

Thank You