Research in Chemistry Education and its implications for teaching and learning of Chemistry at tertiary level

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Outline

1. Genesis of Chemistry Education Research (CER)

2. Chemistry as a Domain and its Learning Difficulties

3. Areas of research in CER with special emphasis on CER at tertiary level

4. Other Developments that demand innovations in chemistry education at tertiary level

5. CER ideas and innovation in instructional methods at tertiary level

6. Tertiary Chemistry education scenario in India and CER (including the work at HBCSE)

Genesis: Chemistry Education Research (CER)

Around 1960s

Interesting Developments: psychology (Ausubel, Piaget, Vygotsky)

Photos
https://en.wikipedia.org/wiki/Jean_Piaget
https://notendur.hi.is//~joner/eaps/wh_ausub.htm
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 mechanical based) became central to the curricula

CER /Genesis

Curricula projects

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 Chemistry Education (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

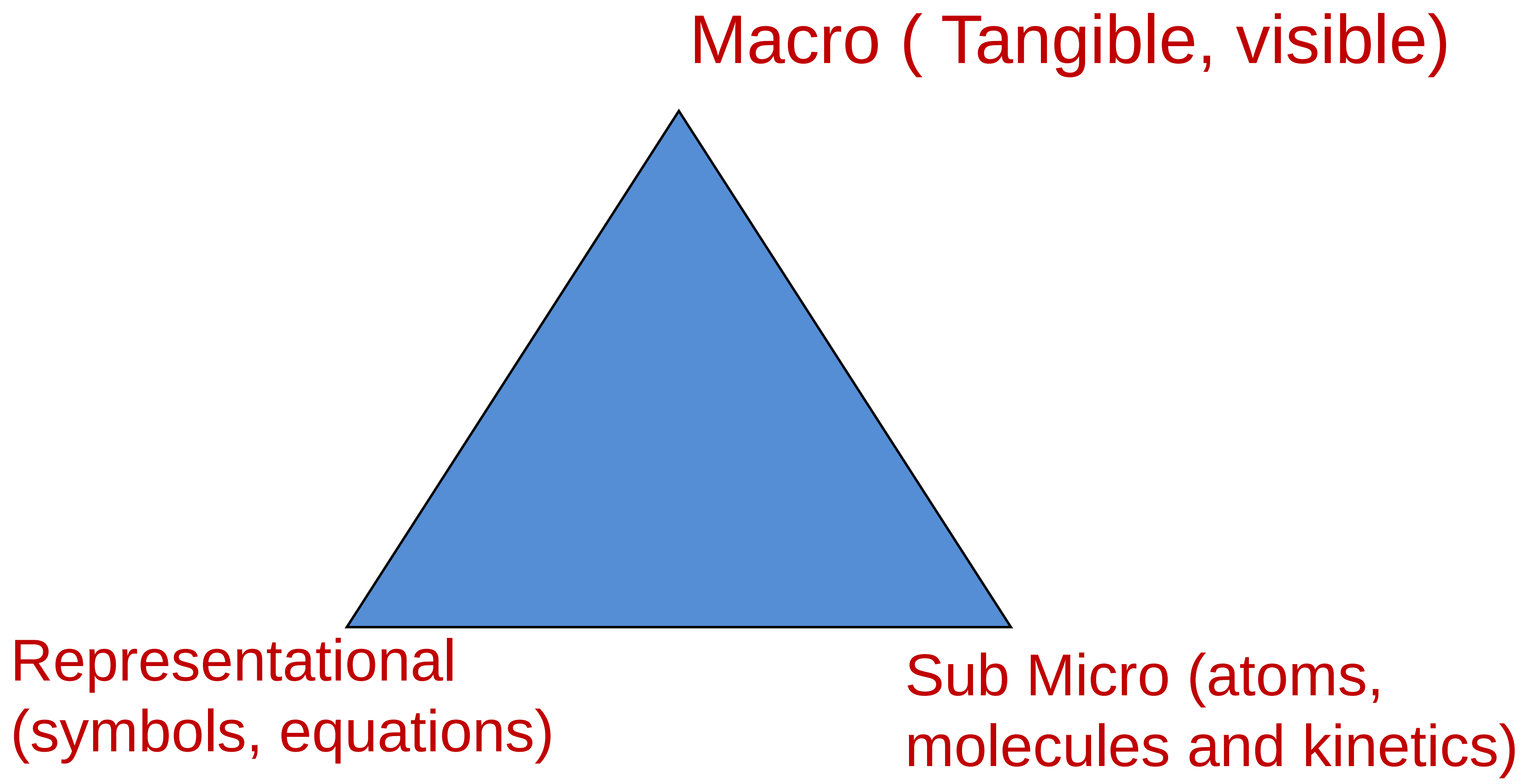
Informed by

- 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.

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 deals with properties of substances and its transformations.

Descriptive chemistry relies on qualitative aspects of matter e.g. colour, smell, odour

Class concept in chemistry e.g. acids, bases, elements help to investigate and classify new substances.

Descriptive chemistry: based on development and revision of empirical models – important and essential in chemistry e.g. Arrhenius model , Bronsted-Lowry model

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

Chemistry as a Domain

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 give rise to huge difference in properties

Advances from Dalton to Quantum mechanics (QM)

QM model has become more central and is very mathematical.

Learning Difficulties

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

Teaching - How to introduce such concepts and communicate them in accessible manner is challenging.

Several plausible explanations exist in chemical system-

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

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

Learning Difficulties

In simple words, at least in practice, chemistry can not be completely reduced to physics even at sub-micro level.

Basically, chemistry epistemology can not be equated to that of physics.

The inadequacy of earlier curriculum reforms probably was due to lack of appreciation of this point.

Erduran, S.& Scerri, E. (2002), The nature of chemical knowledge and chemical education, in Gilbert, J.K. (eds.), Chemical Education: Towards Research- based Practice , 7-27.,Kluwer Academic press, The Netherlands

Areas of Research in CER

Areas of Research in CER

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

CER-Areas

Three Latest reviews

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

Major Work done at University level (Teo *et al.*- 2014)

353 papers in higher education, 163 pre-university level

Location of the studies (Teo *et al.*- 2014)

North/Central America (48%), Europe (35%), Asia(11%), Oceania(4%), Africa (2%)

Methodology: both qualitative and quantitative methods

Less explored areas (Teo *et al.*- 2014)

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

1. Conceptual Understanding/Misconceptions

Most dominant trend (from 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)

2.Pedagogy

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

Process Orientated Guided Inquiry learning (POGIL):
based on learning Cycle Approach
(explore- build-apply)
(www. pogil.org)

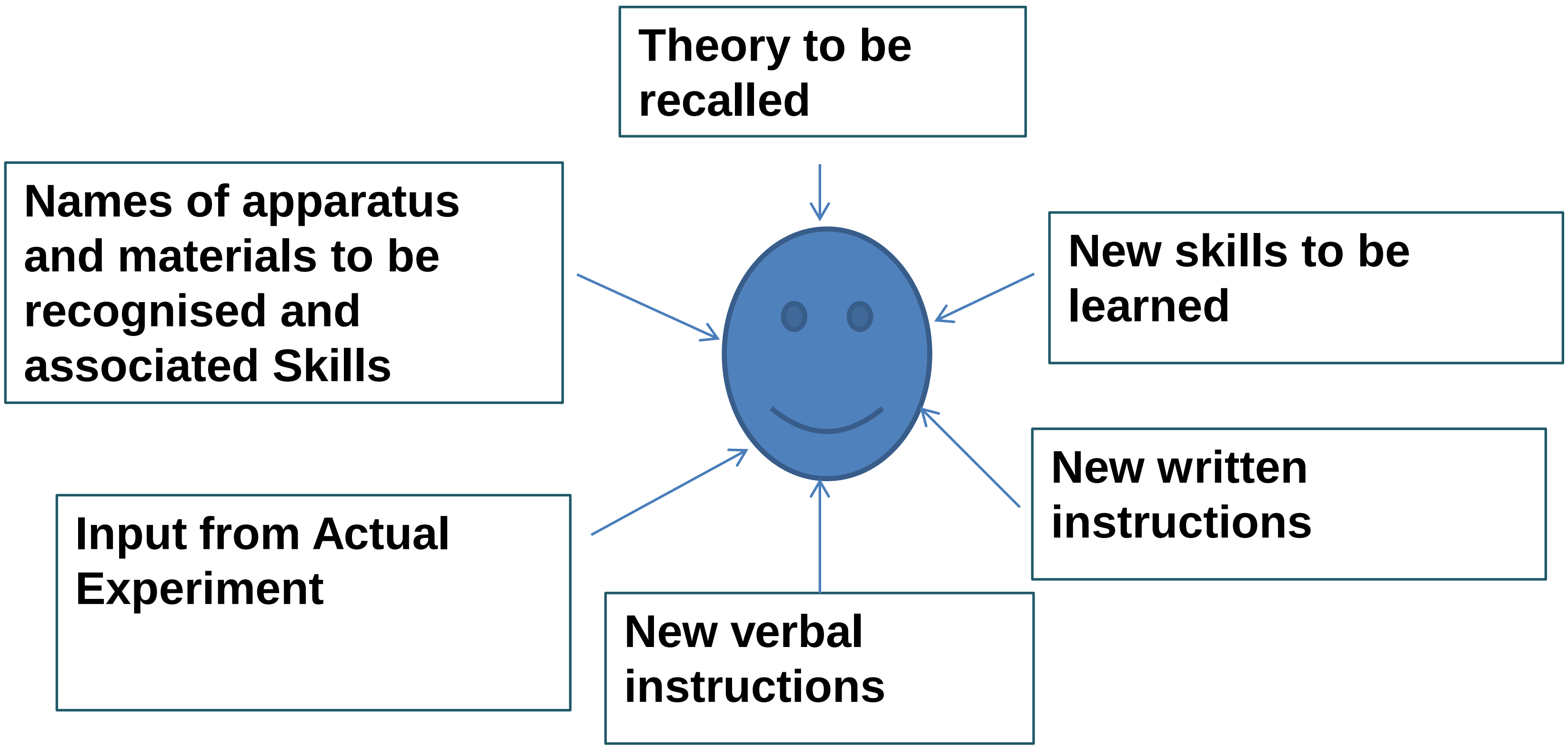
Peer Led Team Learning (PLTL)
(https://sites.google.com/site/quickpltl/)

3. Learning in Chemistry Laboratories

What is the Role of the laboratory in learning ?

Expository (Traditional): students involved in lower order cognitive processes – no learning

Overload on memory



Chemistry Laboratories

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

  (open and guided inquiry, problem based laboratories interesting context)

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

3. 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, working in group is better)

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

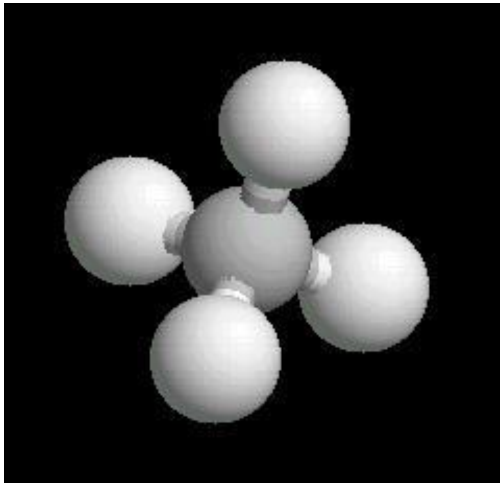
4. Representations in chemistry

Visualization and representations is central to chemistry (Particulate Nature Of Matter)

Major observation:

Model is perceived as reality

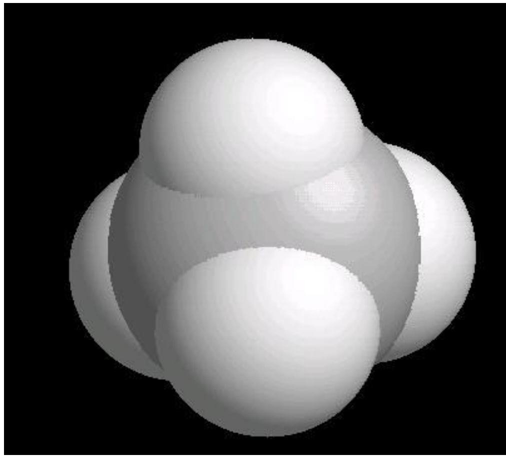
Concrete models -can be touched (objects)



Computer based :

Help students to understand models as mental constructs

3D animations facilitate understanding better than 2D better than static visuals



Images
http://www-personal.umich.edu/~lpt/Modeling/lab15.htm

Representations

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

Relationship between Spatial ability and success in Chemistry (work done in Organic chemistry)
Mixed results are obtained

CER-Less explored aspects

Conceptual Understanding

- Investigating Instructional strategies that can be used to tackle specific misconceptions
- Robust evidence about the conceptual change and duration for which it lasts (Longer and longitudinal studies)
- Studies related to transfer of knowledge
- Studies in interdisciplinary areas

Chemistry Laboratory

- Studies related to - What learning outcomes (cognitive, psychomotor and affective) can be achieved and assessed in laboratory?

CER-Less explored aspects

Problem solving

- Problems in organic chemistry (have only representations and no calculations)
- Problem representation (surface features have impact on novices)
- Open-ended problems

Representations

- More research is needed on animations, simulations and technology–enhanced techniques that facilitate visualizations and representations
- About conditions under which they are effective

Other Developments that demand innovations in chemistry education at tertiary level

Developments

Simultaneous- to rise of CER

- Rapid growth in research at University and industries
- Chemistry became interdisciplinary (interactions with domains such as pharmacy, Environmental science etc.)
- Scale of chemical reactions (nano to tonnes)
- Advances in Information and communication Technology (ICT) - sophisticated analytical Instruments (measurements and modeling in chemistry), change in laboratory practices,

For chemistry curricula: what is to be included in syllabus?

Goedhart, M. J. (2015). Changing perspectives on the undergraduate chemistry curriculum. In: García-Martínez, J. & Serrano-Torregrosa, E. (Eds.), *Chemistry Education: Best practices, Opportunities and Trends.* Wiley VCH: Weinheim, Germany.

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Developments

- Large number (from diverse background) - students entering in chemistry education at tertiary level
- Tie-up among Universities / Accreditation of courses: demands compatibility in higher education
- Demands from Employers (Tie –up between Universities and industries)

Chemistry Education

- Interactions of teachers and students got reduced
- Traditional (lecture and laboratory) mode of teaching still dominates
- Balancing of local and global dimensions
- Transferable skill should be taught

CER ideas and innovation in instructional methods at tertiary level

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

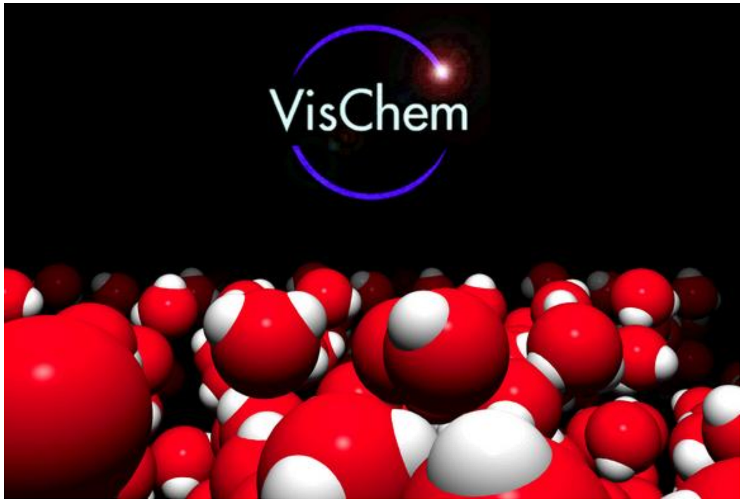
Chemistry laboratory

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

Context and problem based learning (problems present context- focus on subject content that will be learnt)

CER ideas and innovative instructional methods

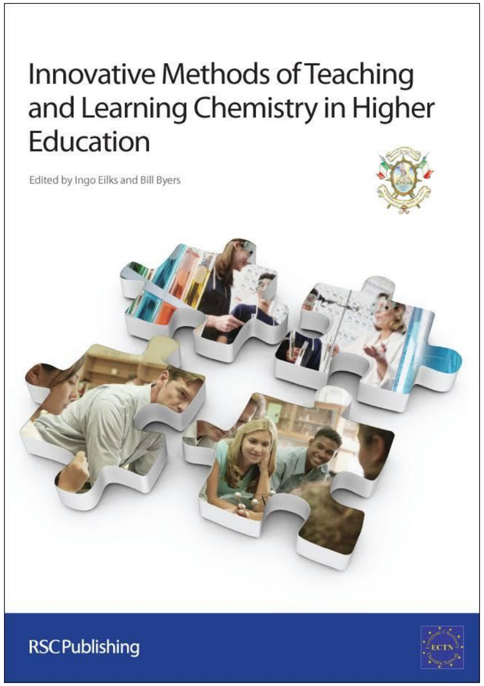
Multi-media support: Multiple representations- for better Conceptualization of sub-micro aspect,
solving real life situations
(http://www.vischem.com.au/)
Roy Taskar



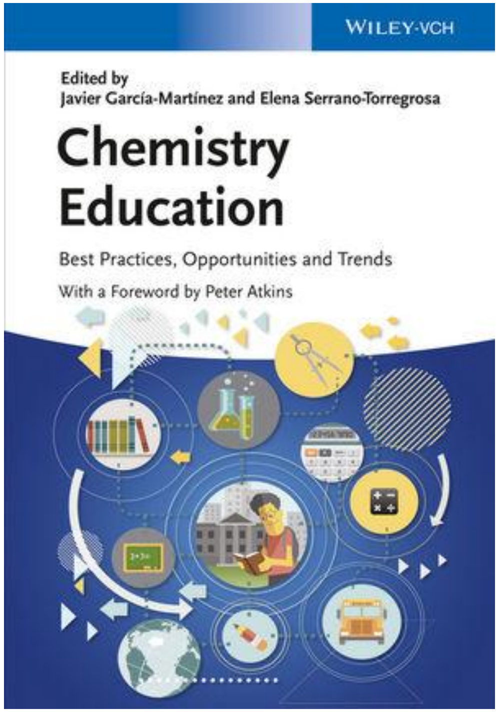
Other roles of ICT

- Laboratory techniques (video)
- Functioning of advanced instruments(simulations)
- Virtual laboratories
- Uploading lecture content/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
http://as.wiley.com/WileyCDA/WileyTitle/productCd-3527336052.html

Chemistry Education scenario at Tertiary level in India and CER

Chemistry Education: Indian Scenario

Major changes in undergraduate science education to address disconnect between research and undergraduate chemistry (science) Education

Launching of several new institutions offering integrated B.S-M. S. programmes in sciences

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), IIRBS (Kerala),

Launching of exchange programmes with Universities abroad

State Colleges : becoming autonomous

What changed ?

- Interdisciplinary areas are introduced as part of curricula
- Students study different areas of sciences for two Years (IISER model),
- Excellent laboratory facilities (experimental)
- Autonomy to plan curricula, execution, assessments
- Sizable young population entered in teaching of chemistry
- Realisation of the fact that university and college teacher development is crucial for future of higher education

Chemistry Education: Developmental Efforts in India

Considerable R&D activity in Chemistry education is under way at many places in India

Low cost Equipment project (IUPAC/ UNESCO)
(K.V.Sane, University of Delhi, 1980s)

Green Chemistry drive by Department of Science and Technology (DST)

Green chemistry Network centre (http://greenchem.du.ac.in/)
Prepare and disseminate the educational materials on Green chemistry for school, college and university levels

Developmental Efforts in India

Teaching Learning Centre (IIT Madras, 2011)

(http://tlc.iitm.ac.in/welcome.html)

Assisting faculty to become conversant with research-based, practically proven methodologies

E- material through ICT

National Mission on Education through ICT (2006)

(http://www.sakshat.ac.in/aspx/frmrelatedlink.aspx)

Virtual Laboratory in chemical sciences (http://vlab.co.in/)

National Portal on Technologically Enhanced learning (NPTEL)

(http://nptel.ac.in/) (first phase -2003, idea generated-1999)

E-content for post graduate courses (2015, chemistry)

(http://epgp.inflibnet.ac.in/)

CERD work at HBCSE

CERD work at HBCSE

Research

- Students' Conceptions in periodic table and chemical equations (1990s)
- Students conceptions in elementary thermodynamics (on going: predict-observe-explain approach)
- Cognitive research about representational competency in chemistry (on-going: eye-tracker studies)

Programmes for Chemistry Teachers
(Conducted as part of Chemistry Olympiad programme)
Chemistry Teachers
Pre-university / University

Designing Problems -(long thematic context based questions)
Experiments- Unconventional ways, safety in laboratory,
Assessment

National Initiative on Undergraduate Science (Chemistry) involves nurture of UG students and teacher orientation

Developmental work

Instructional material (Physical chemistry)

Thermodynamics

1. Student workshops and study circle: interactions with undergraduate chemistry students, to teach and understand their conceptions through questionnaires etc.
2. Developing innovative instructional material based on insights from 1. A comprehensive instructional book on chemical thermodynamics has been developed

POGIL

Organic chemistry: collaboration among HBCSE and teachers from local colleges (also core topics in Analytical/Physical)

CERD/HBCSE

Laboratory activities

How do you change the existing laboratory activities?

Ongoing work

Experiments - We are getting feedback about how do students receive them ? (mainly tested at HBCSE –yet to be tested with regular colleges)

Developing experiments for undergraduate chemistry Laboratory with emphasis on green chemistry (Teachers have joined us as mentors –very few)

Future Direction

As part of our efforts to improve chemistry education at the national level, we launched International Conference on Education in Chemistry (ICEC) in collaboration with Association of chemistry Teachers (ACT).(hosted in 2010 and 2014)

Aims

- To bring awareness to chemistry teachers at tertiary level in India about CER work
- To support and network ongoing CER work (university / pre-university)

Acknowledgements

- Members of Chemistry cell at HBCSE

- Colleagues at HBCSE (Sugra Chunawala, Arvind Kumar)
- Colleagues from local colleges of Mumbai and Pune involved with chemistry activities at HBCSE
- Students under NIUS chemistry

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- 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.

Thank You