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)
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
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

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

\( \text{CH}_3\text{-CH}_2\text{-OH} \) and \( \text{CH}_3\text{-O-CH}_3 \) (same formula- \( \text{C}_2\text{H}_6\text{O} \)) – 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.

Areas of Research in CER
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1. Conceptual understanding/Misconceptions
2. Pedagogy
3. Learning in chemistry laboratory
4. Problem solving
5. Representations in chemistry
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 (H₂, 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

- Names of apparatus and materials to be recognised and associated Skills
- Input from Actual Experiment
- Theory to be recalled
- New verbal instructions
- New skills to be learned
- New written instructions
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)

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)

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?

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
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
Chemistry Education scenario at Tertiary level in India and CER
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
Indian Scenario

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


E-content for post graduate courses (2015, chemistry) (http://epgp.inflibnet.ac.in/)
CERD work at HBCSE
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Research

- Students’ Conceptions in periodic table and chemical equations (1990s)
- Students conceptions in elementary thermodynamics (ongoing: predict-observe-explain approach)
- Cognitive research about representational competency in chemistry (ongoing: 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)
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)
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• 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.

Thank You