Embedded/formative/diagnostic assessment in science to engender deeper conceptual understanding

David Treagust
Curtin University of Technology
Perth, Australia

11-12 September 2008

Science and Mathematics Education Conference 2008

Dublin

Overview of Presentation

Context

- **Science enrolments**
- **Current educational reforms**
- **Assessment in the context of educational reforms**

Need for alternative forms of assessment

- **Formative/embedded assessment**
- **Two-tier multiple-choice diagnostic instruments**
- **Illustrate how these tests can make an important contribution to improving teaching and students' learning**

Problems

- Continuing low participation rate of students taking science at secondary and tertiary levels in most western nations
- Especially last two years of school and more conceptually demanding calculus-based options that lead to acceptance in university science and engineering courses
- Decline in interest in science and engineering studies in many OECD countries (International Conference Amsterdam November 2005)
- Sometimes, sharp declines in enrolments

  - Chemistry in the UK – 25%

  - Physics in France - 46%

Problems

- **The success, and even the continuation, of science programs at university are dependent on foundational improvements in science education in secondary schools and primary schools**
- **What do we know about teaching and learning science?**

Students' Alternative Conceptions

- Three decades of research about students learning science
- The majority of students have only a limited understanding of science concepts following instruction
- Students construct sensible and coherent understandings of phenomena and concepts do not match the views that are universally accepted by the scientific community
- Resulting misunderstandings can interfere with subsequent learning
- Students develop inappropriate understanding of new concepts

Assessment in The Context of Current Reforms

- **Reforms in science education are taking place worldwide (e.g. in USA, UK, Taiwan, Singapore, Australia, Brunei, Ireland)**
- **Increasing awareness that science curricula offered in schools are not meeting students' needs**
- **Reforms need to involve assessment as well as curricula and teaching approaches**
- **But reforms will be less effective unless assessment matches changes in curricula and teaching**

Functions of Assessment

- ***Direct assistance*** **to individual students and to teachers**
- ***Certification*** **of individual students**
- **Public *accountability* of educational institutions and their teachers**
- **Assessment can be Diagnostic, Formative and Summative**

(Note: Most investment in assessment and testing is generally devoted to the *certification* and *accountability* functions)

Effects of Summative Assessment

- Can dominate classroom work
- Distorts teaching by narrowing learning opportunities
- Misrepresent the nature of the subject
- Underscore inequities in education
- Results in not using good diagnostic/formative assessments
- Belief that summative assessment enhances student success

Features of Diagnostic Assessment

- Central to good teaching and learning
- Encourages explanations
- Consistent with current learning theories
- Helps monitor understanding
- Often requires a change in attitude and practice of teachers

Distinguishing Features of Diagnostic/Formative Assessment from Summative Assessment

- Information gathered needs to be acted upon
- Information used by both teachers and students
- Information enables teachers and students to modify how they teach and learn
- Information enables teaching and learning to be more effective

Requirements for Effective use of Diagnostic/Formative Assessment by Teachers

- **Integration of testing and instruction – *embedded* assessment**
- **Clear conception of curriculum intention**
- **Clear conception of the goals and process of instruction**
- **Understanding of theories of instruction and learning**
- **Better understanding of how students learn**

Need for Alternative Assessment Methods

Majority of teachers do not effectively diagnose students' learning problems, especially at an early stage of learning

- **To address students' learning needs, teachers can include specially designed assessment procedures in their instructional repertoires**
- **Need for a wide range of both formative and summative assessment methods to gain feedback on student learning**
- **Most effective methods are very time consuming and not practical for busy classroom teachers**

Need for Alternative Assessment Methods

- Research evidence that experienced teachers frequently do not appreciate the problems encountered by students in learning complex science concepts
- Regular approaches to instruction do not probe sufficiently for reasoning of answers
- Usual assessment procedures do not demand such detailed explanations of concepts
- But use of these diagnostic instruments and subsequent change in teaching does not guarantee that alternative conceptions will not be constructed and retained by students

Examples of Diagnostic/Formative Assessment Strategies used in Classroom Teaching

- Written question to start each lesson
- Written exercises/explanations
- Reciprocal reading
- Sentence writing with given words
- Quizzes
- Labelling diagrams
- Annotated diagrams
- Multiple-choice items
- Concept maps
- Concept cartoons
- Predict-Observe-Explain (POE)
- Two-tier multiple-choice items

General Point - the Need for Effective Embedded/Formative Assessment

- **One case study in Michigan school with Grade 8 students studying sound**
- **Science teacher consistently used**
  - **Written pretest to start the lesson**
  - **Wide range of questioning types**
  - **Experiments**
  - **Individual writing tasks**
  - **Group writing tasks**
  - **Students develop models**

(Treagust, D. F., Jacobowitz, R., Gallagher, J. J., & Parker, J. (2003). Embed assessment in your teaching. *Science Scope, 26*(6), 36-39)

One Approach to Address the Problem

- **Present science and its assessment so that students better question and understand the underlying science concepts**
- **Students encouraged to think about the concepts and consider alternative explanations rather than memorise basic facts for a test or examination which are then forgotten.**
- **Planned formative/embedded assessment using multiple-choice diagnostic items**
- **Applying research findings to classroom practice**

Development of Two-tier Diagnostic Tests

Three major aspects to developing these items:

- **Content defined and represented in a concept map that accommodates the propositional statements**
- **Information about students' conceptions is obtained from**
  - **extant research literature**
  - **students' free response explanations to first tier**
  - **conducting unstructured interviews with students who have been taught the content/concepts**
- **The development of the two-tier multiple-choice diagnostic items**

Item 2 of the *Photosynthesis & Respiration Diagnostic Instrument*

Which gas is taken in by green plants in large amounts when there is no light energy at all?

1 carbon dioxide gas

2 oxygen gas

The reason for my answer is:

A This gas is used in photosynthesis which occurs in green plants all the time.

B This gas is used in photosynthesis which occurs in green plants when there is no light energy at all.

C This gas is used in respiration which only occurs in green plants when there is no light energy to photosynthesise.

D This gas is used in respiration which takes place continuously in green

Students' responses to Item 2 of the *Photosynthesis & Respiration Diagnostic Instrument*

Year	N	Choice	Reason					No reason	Total (%)
			A	B	C	D	E		
8	137	1	14.6	16.8	10.9	16.1	-	2.9	61.3
		2	7.3	10.2	11.7	8.8*	-	0.7	38.7
9	88	1	11.4	5.7	20.5	17.0	-	1.1	55.7
		2	3.4	18.1	11.4	11.4*	-	-	44.3
10	99	1	8.1	11.1	11.2	24.2	4.0	-	58.6
		2	3.0	8.1	23.2	7.1*	-	-	41.4
11	68	1	7.4	1.5	8.8	17.6	-	-	35.3
		2	1.5	1.5	33.8	27.9*	-	-	64.7
12	49	1	-	-	6.1	6.1	-	-	12.2
		2	-	-	14.3	65.3*	4.1	4.1	87.8

Item 5 of the *Photosynthesis & Respiration Diagnostic Instrument*

Respiration in plants takes place in ….

1. the cells of the roots only.
2. every plant cell.
3. in the cells of the leaves only.

The reason for my answer is:

A. All living cells need energy to live.

B. Only leaves have special pores (stomates) to exchange gas.

C. Only roots have small pores to breathe.

D. Only roots need energy to absorb water.

Students' responses to Item 2 of the *Photosynthesis & Respiration Diagnostic Instrument*

Year	N	Choice	Reason					No reason	Total (%)
			A	B	C	D	E		
8	137	1	5.1	0.7	-	4.4	-	-	10.2
		2	42.3*	3.6	0.7	2.9	-	1.5	51.1
		3	6.6	29.2	1.5	0.7	-	0.7	38.7
9	88	1	-	-	-	1.1	-	2.3	3.4
		2	38.6*	-	-	-	-	-	38.6
		3	8.0	46.6	3.4	-	-	-	58.0
10	99	1	2.0	-	3.0	5.1	-	2.0	10.1
		2	37.4*	3.0	1.0	-	-	-	41.4
		3	3.0	41.4	3.0	1.0	-	-	48.5
11	68	1	-	1.5	-	-	-	-	1.5
		2	58.8*	-	-	1.5	-	-	60.3
		3	4.4	33.8	-	-	-	-	38.2
12	49	1	-	-	-	-	-	-	0.0
		2	87.8*	-	-	-	2.0	-	89.8
		3	-	8.2	-	-	2.0	-	10.2

Common Alternative Conceptions of Photosynthesis and Respiration

- Respiration in green plants takes place only during the day
- Photosynthesis occurs in green plants all the time
- Green plants make their food from oxygen gas in the presence of sunlight
- Respiration in plants takes place in the cells of the leaves since only leaves have special pores to exchange gases
- Green plants respire only at night (when there is no light energy)

Item 1 of the *Covalent Bonding and Structure Diagnostic Test*

Which of the following best represents the position of the shared electron pair in the HF molecule?

1) H : F **2) H : F**

Reason:

A) Non-bonding electrons influence the position of the bonding or shared electron pair.

B) As hydrogen and fluorine form a covalent bond the electron pair must be centrally located.

C) Fluorine has a stronger attraction for the shared electron pair.

D) Fluorine is the larger of the two atoms and hence exerts greater control over the shared electron pair.

Students' responses to Item 1 of the *Covalent Bonding and Structure Diagnostic Test*

Year	Choice to first part	Reason			
		A	B	C	D
11	1	1.3	2.5	43.4*	5.0
	2	6.3	33.3	8.2	-
12	1	-	3.7	61.4*	2.4
	2	2.4	22.9	7.2	-

Item 1 from the *Chemical Bonding Diagnostic Test*

Sodium chloride exists as a molecule.

I True II False

Reason:

A The sodium atom shares a pair of electrons with the chlorine atom to form a covalent bond.

B The sodium ion forms a molecule with the chloride ion.

C Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.

D Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.

Students' responses to Item 1 of the *Chemical Bonding Diagnostic Test*

Choice to first part	Reason			
	A	B	C	D
I	22.5	46.1	7.8	3.9
II	1.0	1.0	16.7*	1.0

Common alternative conceptions of chemical bonding held by 15-16 years old students (N = 119)

Alternative conception	Choice combination	% of students with alternative conception
Bonding		
Metals and non-metals form molecules	**Item 1 [1]**	**80**
Metals and non-metals combine to form molecules consisting of oppositely charged ions	**Item 1 [1B]**	**46**
Atoms of a metal and a non-metal share electrons to form molecules	**Item 1 [1A]**	**23**

Common alternative conceptions of chemical bonding held by 15-16 years old students (N = 119) (cont.)

Alternative conception	Choice combination	% of students with alternative conception
A metal is covalently bonded to a non-metal to form a molecule	Item 6 1[A]	18
Metals and non-metals form strong covalent bonds	Item 6 [1D]	10
Ionic compounds exist as molecules formed by covalent bonding	Item 4 [1B]	14
In ionic bonding, the number of electrons transferred depends only on the number of electrons that the atoms of the non-metal need to achieve a stable octet	Item 3 [1D]	10

Item 14 from the *Representational Systems & Chemical Reactions*

When powdered zinc is added to blue aqueous copper(II) sulfate and the mixture shaken, the blue colour of the solution gradually fades and becomes colourless. At the same time a reddish-brown deposit is produced. The chemical equation for the reaction that occurs is

$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$,

while the ionic equation is

$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$.

Why did the solution finally become colourless?

1 Copper has formed a precipitate.

2 Zinc is more reactive than copper(II) sulfate.

3 The copper(II) sulfate has completely reacted.

4 Zinc has dissolved, just like sugar dissolves in water.

The reason for my answer is:

A Zinc ions are soluble in water.

B Zinc loses electrons more readily than copper.

C Soluble, blue Cu^{2+} ions have formed insoluble, reddish-brown copper atoms.

D In aqueous solution Cu^{2+} ions produce a blue solution, while Zn^{2+} ions produce a colourless solution.

Students' responses to Item 14 *(N = 65)*

Choice	Reason				
	A	B	C	D	Total (%)
1			4.6	6.2	11
2		4.6	3.1	10.8	18
3		3.1	23.1	*40.0	66
4				4.6	5

Learning Difficulties Identified in the *Representational Systems & Chemical Reactions*

Metal combustion

Mg^{2+} ions (sub, sym) are present in magnesium ribbon (mac) – 14%

Neutralization

The ionic equation (sym) for the reaction between strong acids and alkalis (mac) depends on the stoichiometry of the chemical equation (sym) – 11%

Copper(II) oxide (mac) does not contain ions because it is in the solid state; Cu^{2+} ions (sub, sym) are produced only in aqueous solution when it reacts with dilute acid – 25%

Metal-ion displacement

Individual Cu^{2+} ions (sub, sym) in aqueous solution are blue (mac); when Cu^{2+} ions are displaced, insoluble (mac) copper atoms, Cu, are produced (sub, sym) – 31%

Learning Difficulties Identified in Inorganic Chemistry
Qualitative Analysis Diagnostic Instrument

Displacement

A more reactive ion displaces a less reactive ion in a double decomposition / precipitation mixture - 25%

Redox

A redox reaction occurs in a double decomposition reaction involving the use of alkalis - 13%

Heating solid substances

All gases have to be tested when a substance is heated. - 23%

Ionic compounds have strong bonds and do not decompose on heating - 26%

Item 8 from *Chemical Equilibrium Diagnostic Test*

If you have a 0.5M solution of sodium chromate ($Na_2Cr_2O_7$) in which the following equilibrium is established

$$CrO_4^{2-}(aq) + 2H^+(aq) \leftrightarrow Cr_2O_7^{2-}(aq) + H_2O(l)$$

yellow **orange**

And you add 10 mL of 0.5M solution of sodium dichromate to the original solution, what would you observe?

A. The solution becomes yellow.
B. The solution becomes deeper orange.
C. The solution remains unchanged.

Reason

1. To counteract the increased amount of $Cr_2O_7^{2-}(aq)$ the system will form more $CrO_4^{2-}(aq)$.
2. There will be more collisions between particles of $Cr_2O_7^{2-}(aq)$ and $H_2O(l)$.
3. Due to increase in $Cr_2O_7^{2-}$ Q will be greater than K.
4. There is no change in concentration of any species.
5. The value of the ratio expressed by Q is unchanged.
6. Due to increased volume there will be less collisions between particles.

Letters from Chemistry Professors

We had just completed our studies on *Chemical Bonding and Structure* and students were preparing for mid-term examinations. On most items, less that 50% selected the correct answer and the correct reason. I was very surprised! Now that I know they have problem I can make some attempt to deal with it.

Your paper gives hope to those of us who would like to be able to evaluate "misconceptions" with a simple pen and paper exam. Would you send me a copy of the test you designed and used? I would like to test some students and use it as a model of an examination to evaluate "misconceptions" on the topic "chemical equilibrium".

Available tests - not all prepared by my colleagues and me

- Photosynthesis and respiration (Haslam & Treagust, 1987)
- Diffusion and osmosis (Odom & Barrow, 1995)
- Breathing and respiration (Mann & Treagust, 1998)
- Internal transport in plants & the human circulatory system (Wang, 2004)
- Flowering plant growth and development (Lin, 2004)
- Covalent bonding and structure (Peterson, Treagust & Garnett, 1989)
- Chemical bonding (Tan & Treagust, 1999)
- Qualitative inorganic analysis (Tan, Treagust, Goh, & Chia, 2002)
- Chemical equilibrium (Tyson, Treagust & Bucat, 1999)
- Multiple representations in chemical reactions (Chandrasegaran, Treagust & Mocerino, 2005)
- Ionisation energies of elements (Tan, Taber, Goh & Chia, 2005)

Available tests - not all prepared by my colleagues and me

- Acids and bases (Chiu, 2001, 2002)
- States of matter (Chiu, Chiu & Ho, 2002)
- Light and its properties (Fetherstonhaugh & Treagust, 1992)
- Formation of images by a plane mirror (Chen, Lin & Lin, 2002)
- Forces (Halloun & Hestenes, 1985)
- Forces (Hestenes, Wells & Schwackhamer, 1992)
- Electromagnetism (Paulus & Treagust, 1991)
- Electrical circuits (Millar & Hames, 2001)
- Force, heat, light and electricity (Franklin, 1992)
- Kinetic particle theory and chemical bonding (Othman, Treagust & Chandrasegaran, 2008)
- Electrolysis (Sia, Treagust & Chandrasegaran, …)
- Kinetic particle theory, osmosis and diffusion (Nawaf & Treagust, ….)

Implications for Science Teaching and Learning

- Completed test items can be used for class discussion to illustrate various viewpoints, enabling students to reflect on their own ideas and examine their own conceptual thinking

- Addresses concerns about current assessment practices, especially formative/embedded assessment

- Enables science teachers to better assess/diagnose students' understanding of specific science content

Implications for Science Teaching and Learning

- Increase science teachers' awareness of students' alternative conceptions for improved teaching
- Results provide useful information for curriculum revisions
- Help maintain students interest in science
- Help maintain students enrolment in science
- Illustrates application of research to classroom practice

Problems with these kind of items and instruments

- Requires good literacy skills
- Requires metacognitive skills
- Requires perseverance
- Academically weaker students do not wish to be so engaged
- Academically stronger students see more options

Implications for Science Teaching and Learning

- Accessibility is important - need to be available via WebCT or CDROM or internet (I am working on this)
- Two tier items recommended as one type of assessment by the American Chemical Society
- Taiwan National Science Concept Learning Study used specially created two tier tests
- New assessment initiative in Brunei has a focus on diagnostic assessment

Some References

Treagust, D. F. & Chandrasegaran, A. L. (2007). The Taiwan. National Science Concept Learning Study in an international perspective. *International Journal of Science Education* (Special Issue), *29*(4), 391-404.

Chandrasegaran, A. L., Treagust, D. F. & Mocerino, M. (2007). The development of a two-tier multiple choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. *Chemistry Education Research and Practice, 8*(3), 293-307.

Tan D K-W., Treagust, D, F. Goh, N-K., and Chia L-S. (2002). Development and application of a two-tier multiple choice diagnostic instrument to assess high school students' understanding of inorganic qualitative analysis. *Journal of Research in Science Teaching, 39 (4)*, 283-301.

Treagust, D. F., Jacobowitz, R., Gallagher, J. J., & Parker, J. (2001). Using assessment as a guide in teaching for understanding: A case study of a middle school science class learning about sound. *Science Education, 85*, 137-157.

Treagust, D.F. (1995). Diagnostic assessment of students' science concepts. In S. Glynn and R. Duit (Eds.), *Learning science in the schools: Research reforming practice* (pp 327-346). New Jersey: Lawrence Erlbaum Associates.