ENHANCING DEEP LEARNING VIA HIGHER-ORDER COGNITIVE SKILLS (HOCS)- PROMOTING TEACHING STRAGEGIES AND ASSESSMENT

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CURRENTLY EVOLVING PARADIGM SHIFTS:

- Growth- to- sustainable developmnt
- Correction-to-prevention
- Wants-to-needs
- Gaps increase-to-gaps-decrease
- Passive “consumption”-to-active participation
- Opyions selection-to-options generation

Selected paradigms shifts in contemporary research and STES-oriented science education

From:	To:
Technological, economical, and social *growth* at all cost…	Sustainable development
Reductionism; i.e., dealing with *in-vitro isolated*, highly controlled, components	Dealing with uncontrolled, *in-vivo complex systems*
Disciplinarity teaching (physics, biology, chemistry, etc.)	Inquiry-based problem solving-oriented, systemic, inter-/cross-/transdisciplinarity
Technological feasibility	Economical-societal feasibility
Scientific inquiry (*per se*)	Socially accountable, responsible and environmentally sound
Algorithmic lower-order cognitive skills (LOCS) *teaching*	"HOCS *Learning*"
"Reductionist" thinking	System/lateral thinking
Dealing with topics in isolation or closed systems	Dealing with complex, open systems
Disciplinary teaching (physics, chemistry, biology, etc.)	Interdisciplinary teaching
Knowing/recognizing/applying of facts and algorithms for solving exercises/tasks	Conceptual (HOCS) learning for problem solving and transfer
Science & technology *per se* (in dealing with sustainability)	Integrative science-social science Education in the STES interface context
Teacher-centered instruction	Student-centered, real world, team learning

Objectives

1. To promote, in science education, the development of evaluative critical system thinking, decision making, problem solving and transfer

2. To teach science for acquiring *new type of flexible, contextually relevant, adaptive knowledge* that facilitate one to cope with the complexity and fragility of multidimensional global socio-economic-technological-environmental political systems via inter- and transdisciplinarity in research and science education and in accord assessment methodologies for sustainable action.

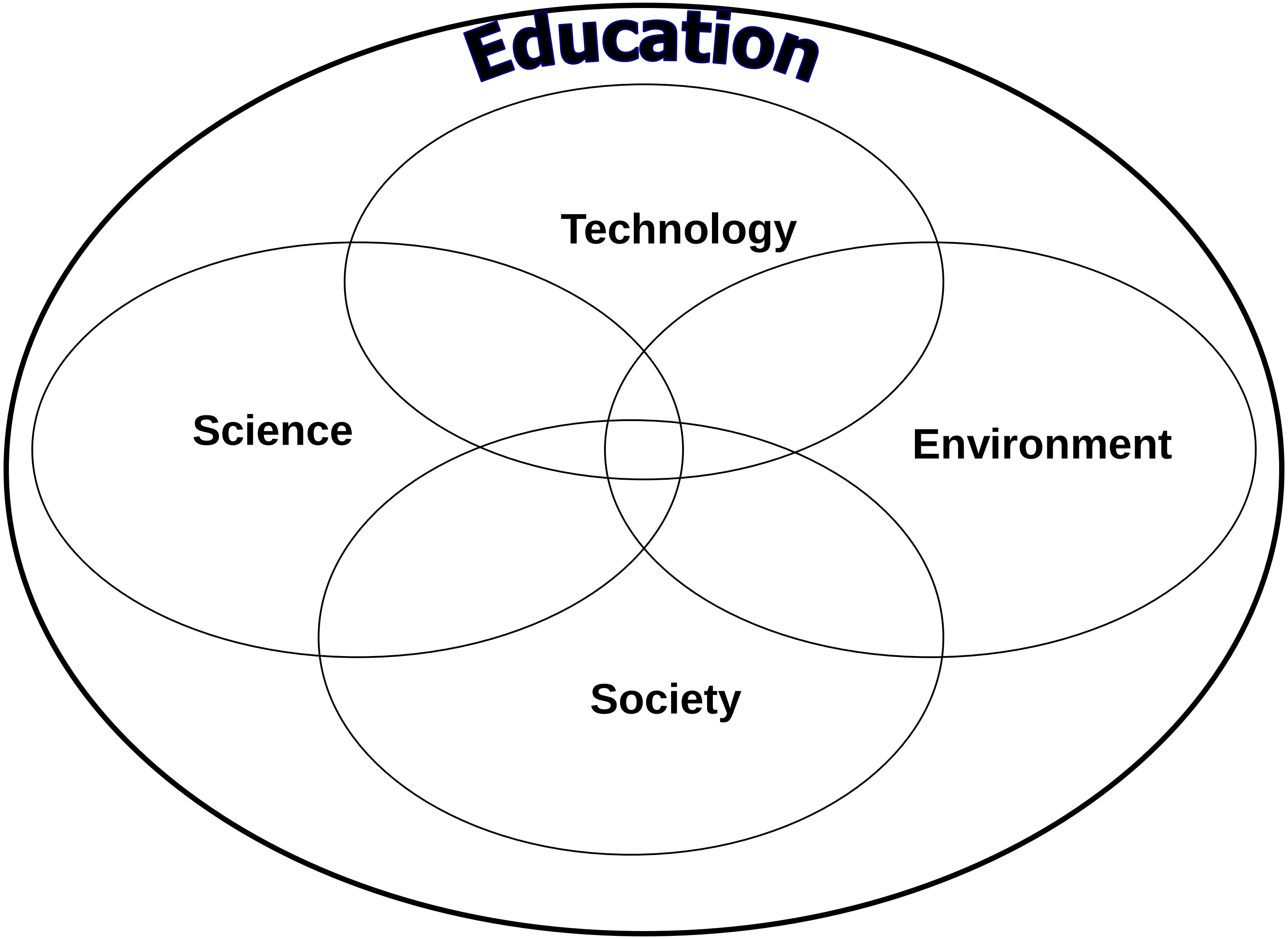

Figure 1: The STES framework for research and education for sustainability

THE GOAL

The “STES Problem Solving – Decision Making Act"

1. Ability to look at the problem and its implications, and recognize it as a problem.
2. Understand the factual core of knowledge and concepts involved.
3. Appreciate the significance and meaning of various alternative possible solutions (resolutions).
4. Exercise the problem-solving act:
   - Recognize/select the relevant data information;
   - Analyze it for its reasonableness, reliability and validity;
   - Devise / plan appropriate procedures / strategies for future dealing with the problem(s).
5. Apply value judgments (and be prepared to defend!)
6. Entertain the DM act:
   - Make a rational choice between available alternatives, or generate new options;
   - Make a decision (or take a position).
7. Act according to the decision made.
8. Take responsibility!

Selected Teaching Objectives

Princeton University President (1993)

…We anticipate our students to:

1. Develop the capabilities of thinking, communicating, convincing and creativity and conceptualize the complexity of a thought…
2. Difference between the important and the trivial…
3. Rationalize critically, systematically…and methodologically
4. Think independently, but dialogly in collaboration with others
5. Maintain political, societal and ethical sensitivity concerning subjects they will be involved in their life

A question to think about:

Does contemporary science education attain the above?

Standardized Expectations Vs. Creative Thinking

Prof. Nel Noddings (Stanford University):

“Providing a complete structure of what is to be learned and a detailed list of outcomes expected of all students results in quick, shallow learning and swift forgetting”

“Students do not come to schools as standard raw material and schools should not expect to produce standard academic products. Education requires initiative and independent thinking not the tedious following of orders that we see in today’s schools”

“Does the current approach to school reform favor the regurgitation of random facts over the development of critical and creative thinking?”

Problem Solving Vs. Exercise Solving

	Problem Solving	Exercise Solving
1	Involved a process used to obtain a best answer to an unknown, subject to some constraints	Involves a process to obtain the one and only right answer for the data given
2	The context of the problem is brand new (i.e., the student has never encountered this situation before)	The student has encountered similar exercises in books, in class, in H.W
3	There may be more than one valid approach	There is usually one approach that gives the right answer
4	The algorithm for solving the problem is unclear	A usual method is to recall familiar solutions from previously solved exercise
5	Integration of knowledge from variety of subjects may be necessary to address all aspects of the problem	Exercises involve one subject and in many cases only one topic from this subject

WHAT SHOULD IT TAKE STRATEGICLY?

A shift-

- From algorithmic lower-order cognitive skills (LOCS) teaching to HOCS learning
- from doing justice to the science discipline (disciplinarity) to doing justice to the learner and the public at large (interdisciplinary/cross-disciplinarity);
- From imparting of knowledge/ “covering material” to conceptual learning/development of transferable HOCS;
- From assessment of passive knowledge to assessment of HOCS; and
- From focusing on “ what should our graduates know” to “what should our graduates be able to do”

THE ECLECTIC EXAMINATION

- a tool for simultaneous assessment of both-courses and students.

consists of:

QUESTIONS-------------------------------to be answered
PROBLEMS--------------------------------to be worked out
TASKS ------------------------------------to be performed
SUGGESTIONS ---------------------------to be developed
IDEAS --------------------------------------to be generated & rationalized
OPINIONS--------------------------------to be defended or rejected
STIMULATIONS ---------------------------to respond to
EXPERIMENTS ---------------------------to be suggested/devised/designed
ALTERNATIVES --------------------------to be chosen and backed consistently

all the above are assembled together in various combinations and in different proportions of each component ----------under variety of conditions in different situations/settings.

& the IEE

EXAMPLES OF (EE AND IEE) QUESTIONS

(Freshman ; General Chem. [Chem 1]; 1st term)

1. The apparent depletion of the stratospheric ozone layer is the reason for the intended ban on the use of freons (CF_nCl_{4-n}) from aerosols and their replacement (at least partially by CO_2.
   - a. Do you think that from a chemical point of view (chemical reactivity and thermodynamical stability) CO_2 is a good substitute of the freons in spite of the *two* carbon-oxygen bonds it contains? Explain.
   - b. If your were assigned the task of finding an appropriate organic or inorganic substitute for freons, what would be your considerations and criteria concerning the *properties and characteristics* of the substitute to be proposed by you? Justify, explain and defend your answer.
   - c. Based on the above, can you come out with any (one or two) specific candidates (i.e., actual organic or inorganic compound(s) to fit the job?) Rationalize and explain.
   - d. Formulate a meaningful question in relation to O_2 and/or O_3 chemistry and answer your question.

2. In your final project you stated: "...it is safe to say that caffeine's effects may be more serious than the general public is willing to admit". Based on the analysis of *your own data and findings*, what are your recommendation(s) concerning caffeine consumption? Provide "hard evidence" to justify your recommendation(s).

(Zoller, 1990)

Taken from a Scientific Journal; 2003

“ Bottled water was found to account for 12% of the cases studied, salad 21% and chicken 31%

The scientists, who were led by Meirion Evans, from the University of Wales, in Cardiff, state: “Eating chicken is a well-established risk factor, but consuming salad and bottle water are not”…

The association with salad may be explained by cross-contamination of food within the home, but the possibility that natural mineral water is a risk factor for campylobacter infection could have wide public health implications”.

Scientists compared 213 campylobacter cases with 1,144 patients who went to their GP with stomach problems but were not infected with the bug. Information was obtained on foods the patients had eaten, animal contact, foreign travel, medical conditions and treatments.

In Europe, legislation states that mineral water must be free from parasites and infectious organisms but, unlike tap water, it cannot be treated in anyway that may alter its chemical composition.

Illustrative LOCS Vs. HOCS- requiring questions

LOCS	HOCS
According to the article: Is the higher mineral content of the bottled water (compared to “ordinary” tap water) responsible for the higher health risk of the former	Suggest a controlled experiment in the lab, via which you’ll be able to unequivocally determine, that the difference in the minerals content between bottled and tap water is not responsible for the difference in their relative health risk
The disinfection of bottles used in the food industry is being done by Cl2 (gas) in basic aqueous solution. Write the reaction mechanism in this oxidation process. Which is the active specie?	Assuming that the reported research has been conducted properly and the presented data are reliable and valid; What, in your opinion, is the reason for the poisonous potential of bottled water? Justify your conclusion.

Q2: *Groundwater pollution by chromium (Cr), the origin of which is industrial disposal, constitutes a real health risk to the public who is using this water. The chromium-containing anions are CrO_4^{2-}, mostly found in neutral water and $HCrO_4$, mostly found in more acidic water. Both are water soluble. Usually, Cr concentrations in groundwater are less than 50 mg/liter. However, in concentrations higher than 500 mg/liter the dominant ion is $Cr_2O_7^{2-}$. In basic water $Cr(OH)_3$ is mainly found. It is less water soluble compared with the previous three and, apparently, less problematic than the other three with respect to its toxicity.*

2.1 *Try to hypothesize a possible reason for the difference, in the extent of risk to the public, between the chromium in $Cr(OH)_3$ compared with that in the first three anionic species* (Question level: HOCS).

2.2 *Suggest a simple experimental lab method via which you may determine the concentration of chromium in basic groundwater samples. Briefly explain how you would do that* (Question level: HOCS).

2.3 *What, in your opinion, will be the effect of acid rain on the relative abundance of the ions CrO_4^{2-}, $HCrO_4^{1-}$, $Cr_2O_7^{2-}$ and $Cr(OH)_3$ in chromium-contaminated ground water? Explain.* (Question level: HOCS).

Assessing Question Asking Capability (Part I)

Read the following paragraph. Formulate three questions that you would like to, or think are important to ask concerning the subject(s) dealt with in the paragraph.

Resources and Energy: What are the Future Options and Alternatives?

Almost every aspect of the Western world is based on the consumption of energy and products derived from the finite crude oil and natural gas resources. There is sufficient reserves of coal that could lead to the production of enough synthetic fuel and gas for the present time. However, energy alternatives (e.g., solar, wind, tide, and waves) should be developed to satisfy the need for the production of electricity. This would involve the substitution of diminishing resources by available non-finite resources. Nuclear energy is another possibility. Future alternatives concerning resource exploitation and energy supply require an in-depth analysis and intelligent decision…and the sooner the better.

Assessing Decision Making Capability (Part II)

2. *In your estimation, is the subject dealt with in the paragraph relevant to you? Explain your answer.*

3. *Can you, based on the given paragraph (and the information it provides), decide on the desirable alternatives of energy supply in your country? Explain your answer.*

4. *In case you think you need more information in order to decide intelligently on the desirable future alternative, formulate two questions that you would ask for answers before making the decision.*

5. *Formulate two criteria that guided you (or will guide you) in your decision concerning the most desirable alternative.*

… Assessing Decision Making Capability (Part II)

6. Briefly explain the pros and cons of the alternative(s) that you have chosen with regard to future implications. Compare your alternative(s) with any other alternatives that you did not choose.

7. In your estimation, are (1) societal and/or (2) values and/or (3) political (distinguished from the scientific-technological-environmental) considerations involved in your decision/choice of the desirable alternative? Relate to 1 and 3 in your answer and explain.

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Our main research-based conclusion is that both - the promotion of question asking (QA) and decision making (DM) HOCS in the STES context - require a purposed longitudinal, persistent HOCS-oriented STES education

College Students' Problem Solving Capability in the Context of Chemistry Teaching

This research focused on 'problems' that require HOCS for their solution in contrast to 'exercises' that require just the application of algorithms (LOCS).

Studied: science majors freshmen's (N=47) pre-post problem solving capabilities within 'traditional' college chemistry teaching which occasionally integrated environment-related, interdisciplinary problems.

Findings: Although most students felt that it is within their capability to solve HOCS-type questions, 'traditional' chemistry teaching does not contribute much to the enhancement of their problem solving capability: students who performed well on the HOCS-type questions were found to: (a) successfully make connections between chemistry-related concepts and STES-oriented issues; (b) express their ideas using multiple representations: textually, qualitatively and quantitatively; (c) present systemic reasoning, where applicable; and (d) evaluate and present several alternative resolutions.

Implementations: a LOCS-to-HOCS shift from exercise-to-problem solving capability, in science education, would require a shift from algorithmic to HOCS-promoting teaching and assessment.

The challenge of STES literacy for sustainability will require:

1. The restructuring of education at all levels (including teacher training programs) towards this new type of *learning* for *all* students, via the implementation of effective research-based HOCS-promoting teaching, assessment and learning strategies.

2. The teaching of how to systemically deal with complex, large systems using extensively the case study methodology

3. Extending interdisciplinary studies and research in such a way so that both students and relevant community "stakeholders" will become capable STES-literate *active participants.*

4. Developing and promoting effective, easily accessible communication and interaction among participants of studies in the STES domains targeting at building a new type of culture that enables a societal process of sustainability-promoting, evaluative, and thinking-based learning.

Summary, Conclusions and Implications

‘HOCS-learning’ targeted at the development and enhancement of STES literacy for sustainability, requires:

- Translating the new goals by all parties involved – stakeholders, policy makers and, mainly, educators – into effective system- and sustainability-oriented educational programs, curricula, courses, teaching, and assessment strategies.
- Ensuring that such system- and sustainability-oriented educational courses and curricula become an integral part of the curricula of formal science, technology and engineering education, which will ensure their recognized (respectable) status.
- Developing and implementing HOCS-promoting assessment strategies as alternatives to the currently dominant (LOCS-oriented) assessment practice in traditional, disciplinary science, technology, the environmental education