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From Teaching-to-Know-to-Learning-to-Think for Sustainability: What Should it Take? And How to Do it?

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Abstract: Given the current striving for *sustainability* and the corresponding paradigms shift in science, technology, R&D, environment perception, economy and politics; e.g., from unlimited growth-to-sustainable development, correction-to-prevention and passive consumption of "goods", culture and education–to active participation, primarily in the science-technology-environment-society-economy-policy (S-T-E-S-E-P) context, the corresponding paradigms shift, at all levels of education is unavoidable. This requires a paradigm shift in conceptualization, thinking, and research in science education, particularly concerning the science-technology-environment-society (STES) interfaces. Consequently, 'STES literacy' requires the development of students' evaluative system thinking and transfer capabilities in this context via the corresponding innovative higher-order cognitive skills (HOCS)-promoting teaching assessment and learning strategies; meaning a shift, within different multicultural contexts, from the currently dominating lower-order cognitive skills (LOCS) algorithmic *teaching-to-know*, to HOCS-promoting *learning-to-think*, typified by students' capabilities of *critical evaluative system thinking* and *decision-making for problem solving and transfer*. This should be consonant with innovative, interdisciplinary *generic*, *contextually bound*, research-based teaching strategies and assessment methodologies leading to "HOCS learning". Our longitudinal research findings and application of this HOCS-promoting science education practice suggest that, although the road to STES literacy for sustainability is rocky, it is educationally doable and, therefore, attainable.

Key words: learning-to-think; LOCS-to-HOCS paradigm shift; science-technology-environment-society (STES) literacy for sustainability

1. Rationale, Conceptualization, Purpose and Objectives

Given the current striving for *sustainability* and the corresponding paradigms shift in science, technology, R&D, environment perception, economy and politics; e.g., from unlimited growth-to-sustainable development, correction-to-prevention and passive consumption of "goods", culture and education-to-active participation, primarily in the science-technology-environment-society-economy-policy (S-T-E-S-E-P) context, the corresponding paradigms shift, at all levels of education is unavoidable. This requires a paradigm shift in conceptualization, thinking, and research in science education, particularly concerning the science-technology-environment-society (STES) interfaces. Consequently, "STES literacy" requires the development of students' evaluative system thinking, and decision making transfer capabilities in this context, via

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the corresponding higher-order cognitive skills (HOCS)-promoting teaching, assessment and learning strategies (Zoller, 1993, 2000; Zoller and Levi Nahum, 2009/2010; Zoller and Scholz, 2004). This means a shift, within different multicultural contexts, from the currently dominating lower-order cognitive skills (LOCS) algorithmic *teaching-to-know*, to HOCS-promoting *learning-to-think*, typified by students' capabilities of *critical evaluative system thinking* and *decision-making for problem solving and transfer*. The HOCS approach to teaching and learning constitutes a comprehensive educational "world outlook" which has been and continues to be research-based implemented in different settings and modifications, at all levels of education, world-wide. The HOCS conceptual model is presented in Figure 1 (Zoller and Levi-Nahum, 2011).

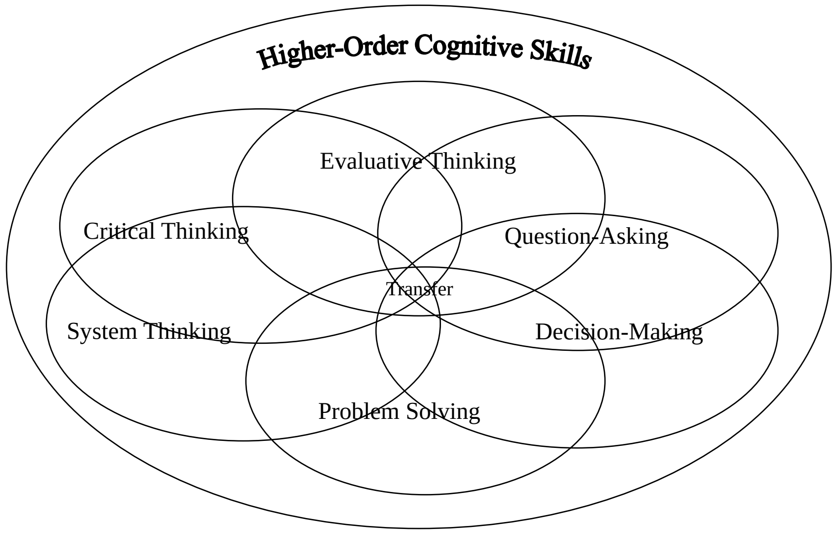

Figure 1 The Guiding Conceptual Model of HOCS in the Context of Science Education

Such a paradigm shift in conceptualization, thinking, research and education, needs to be consonant with innovative, interdisciplinary *generic*, *contextually bound*, research-based teaching strategies assessment methodologies and, in accord, sustainable action–leading to "HOCS learning".

There is an ever-increasing gap between the reality of modern society which is based on science, technology, economy, and advanced, sophisticated networked systems and capabilities and the response of the educational systems, worldwide, to this reality. The educational systems are perceived by students, teachers, parents, society, economical, political and educational systems, as an instructional framework the objective of which is to advance pupils/students up the class ladder, based on their high scored passing of disciplinary, algorithmic *knowledge tests*. "Excelling" is thus measured and perceived according to the "grade achievement" as the exclusive criteria.

The current striving for *sustainability* and the corresponding paradigms shift in almost every aspect within the STESEP context, results in paradigms shifts, at all levels of education, as presented in Table 1 (Zoller, 2009; Zoller and Scholz, 2004).

In the contemporary educational contexts, it implies a paradigms shift in conceptualization, thinking, and research in the context of science education which includes, among others, *novel teaching strategies*, *assessment methodologies* and *learning strategies*, purposed at the development of students' HOCS; among them the capabilities of *Evaluative Thinking* and Decision Making (Zoller, 1993; Tsiparlis and Zoller, 2003; Zoller and Pushin, 2007; Zoller et al., 2010).

Table 1 Selected Paradigms Shifts in Contemporary Research and STESEP-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	Uncontrolled, *in-vivo complex systems*
• Disciplinarity	Problem-solving oriented, systemic inter-/cross-/transdisciplinarity
• Technological feasibility	Economical-societal feasibility
• Scientific inquiry (*per se*)	Socially accountable, responsible and environmentally sound R & D
• Algorithmic lower-order cognitive skills (LOCS) *teaching*	"HOCS *Learning*"
• "Reductionist" thinking	System/lateral thinking
• Disciplinary teaching (physics, chemistry, biology, etc.)	Interdisciplinary teaching
• Teacher-centered, authoritative, frontal instruction	Student-centered, real world, project/research-oriented team learning

Such a state of affairs mandates an *alternative educational practice*, in order to prepare students for a high level of personal and societal performance as motivated citizens inclined to learn and inquire; being active and involved, having the HOCS capabilities of question-asking, evaluative thinking, decision making, problem solving and, most important, taking responsibility for the consequent action and behavior (Zoller, 1993, 1994, 1999, 2000).

In parallel, the overwhelming agreement, worldwide, on the need for a fast transformation in all our life domains, from unlimited development and growth to sustainable development with all the implications involved requires, in accord, paradigms shifts (Table 1), not only in research and scientific, technological-engineering, economical, social, cultural and political practice, but even more so, in purposed education for sustainability and its attainment in all domains of life and human activity within a global web of complex systems, interrelationships and implications in the STES context (Zoller and Scholz, 2004).

The essence of this research- and multi-dimensional educational experience-based paper constitutes an alternative to the existing "traditional" science education practice, aiming at sustainability and excellence for *all*; namely, no more "preparing" students for effective performance, as citizens, in modern societies by imparting disciplinary knowledge via "test wiseness"-oriented LOCS level algorithmic instruction, as the dominant component in the educational system. Rather, the fostering of transfer-oriented "HOCS learning" as the "king's road" for empowering students toward rational, effective, excellence and responsible active participation in whatever role they might play in society. In short: the development of the students' capability of purposed rational-reflective thinking, pre-decision making on what to accept or reject, do or not to do and in what way, and taking a responsible action accordingly; a socially creative and scientifically literate person, having the appetite, readiness and motivation to think, learn, inquire and grow–to compete with him/herself and having the capacity to collaborate with her/his peers (Zoller, 1990, 1993, 2000). Therefore, the nurturing of *excellence for all* in a broad spectrum of fields and contexts is envisioned as a vital overriding goal in the educational system.

2. Objectives, Goal and Related Research Questions

Guided by our 'first approximation' conceptual model (Figure 1) our educational objectives in science education are as follows:

(1) To promote, in science education, the development of *evaluative critical system thinking*, decision making (Levi Nahum et al., 2010), problem solving and transfer.

(2) To teach science for acquiring new type of flexible contextually relevant, adaptive knowledge that facilitates one to cope with the complexity and fragility of multidimensional global socio-economic-technological-environmental-political systems via inter- and trans-disciplinarity in research and science education and in accord assessment methodologies for sustainable action. *The Goal: The "STES Problem Solving–Decision Making Act"* (Zoller, 1990; Zoller and Levy Nahum, 2011); namely,

(a) Ability to look at the problem and its implications, and recognize it as a problem.

(b) Understand the factual core of knowledge and concepts involved.

(c) Appreciate the significance and meaning of various alternative possible solutions (resolutions)

(d) 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).

(e) Apply value judgments (and be prepared to defend!)

(f) Entertain the DM act:

- Make a rational choice between available alternatives, or generate new options;
- Make a decision (or take a position).

(g) Act according to the decision made.

(h) Take responsibility.

Our aims in our related longitudinal active research were: (a) contributing to the body of knowledge on these HOCS; and (b) fostering the shift from algorithmic teaching and assessment to a higher level of cognitive, deep learning. Accordingly, our research aimed at obtaining research-based answers to the following questions:

(1) Does *traditional* science instruction lead to gains in students' HOCS capabilities? (e.g., Evaluative thinking (ET), system thinking (ST), and decision making (DM).

(2) What are the science students' views concerning their capability of resolving HOCS-requiring problems?

What can be learned from students' responses to HOCS-requiring problems, to be used for promoting their generic or disciplinary HOCS capabilities?

3. Selected Relevant Research Findings

Our longitudinal pre/post-based designed research program, within which specially designed questionnaires, relevant to the students' HOCS capabilities studied–were developed, validated and applied. Students' responses were, qualitatively ordinally categorized using a 3-level scale of 0, LOCS-1 and HOCS-2, and followed by the relevant statistics. The essence of the results/findings of such four studies is given in Tables 2-5 below.

HOCS capabilities are enhanced via (a) Tandem implementation of "HOCS promoting" *teaching strategies* and *assessment* methodologies; (b) Such an enhancement requires time; it is not achievable via a single-shot short exercise; (c) The assessment needs not only to be consistent with the science teaching objectives, but also capable of their promotion. This HOCS-promoting instruction and implementation of the corresponding HOCS-level assessment is attainable, and suggests that HOCS development is contextually- but not disciplinary content-bound. Not only can HOCS enhancement be done; it should be done! The issue is–How to Do It?

3.1 Evaluative Thinking

Table 2 Overall Frequencies (%) by LOCS/HOCS Levels of Secondary School Science Students' Responses (Total of 5910) by the Two Sectors (Levy Nahum et al. [submitted])

Cognitive Level	Scoring	Jewish sector (n=2625)	Arab sector (n=3285)	χ^2
No response or irrelevant response	0	18.6%	12.36 %	44.6*
LOCS-level response	1 point	30.1%	73.58%	1111.5*
HOCS-level response	2 points	51.3%	14.06%	951.5*

3.2 System Thinking

Table 3 Means and Standard Deviation in Pre and Post ST Questionnaire of Environment and Science Classes in Both Schools (Kurtam, 2009)

Questionnaire	Trend	N	Mean	SD	T value	P
ST(pre)	Environmental study	43	12.35	2.77	-3.82	0.001
	Science	50	14.86	3.57		
ST(post)	Environmental study	46	16.74	3.12	-0.94	NS
	Science	49	17.75	3.19		

3.3 Problem Solving

Table 4 Students' (N=47) views of HOCS-type problems(Ben Chaim, et al., 2007)

Statements	Mean (on a 1-to-4) likert-type scale	SD
In my opinion, solving this problem is within the capability of beginning science major freshmen.	2.94	0.71
I have full confidence in my response.	2.38	0.67

3.4 Decision Making

Table 5 Participants' Distribution (%) by LOCS/HOCS Level of Questions Asked and the Related Scoring Points (Item-1)

Questions level	Group-T (N_T=105)	Group-4 (N_4=26)	Chi-^{2} test
LOCS	51.38	27.14	DF = 1
HOCS	48.62	72.86	Chi-square value = 12.96
			P < 0.0003
Scoring points			
1 or 2 points	15	8	DF = 2
3 or 4 points	56	20	Chi-square value = 15.87
5 or 6 points	29	72	P < 0.0004

4. What Should It Take? Summary, Conclusions and Implications–for How to Do It

Based on the findings of our longitudinal practice-oriented research, a LOCS-to-HOCS paradigm shift in science chemistry and STES education for sustainability requires:

- Restructuring of education at all levels and science teacher training programs as well;
- Teaching of how to deal with interconnected complex systems and situations;
- A much greater emphasis on inter/cross disciplinarity in teaching and learning;
- A switch from the contemporary dominant algorithmic teaching, to conceptual HOCS-learning;

- The development and implementation of instruments and methodology for contextually-bound HOCS assessment;

meaning, a *should* shift–

- *From* algorithmic lower-order cognitive skills (LOCS) teaching-to-HOCS learning;
- *From* doing justice to the disciplines (disciplinarity) to doing justice to the learner (interdisciplinarity);
- *From* imparting of knowledge/"covering material" to conceptual learning/ development of transferable HOCS;
- *From* assessment of passive knowledge to assessment of HOCS;
- *From* focusing on "what should our graduates know" to "what should our graduates be able to do"–following a pre-critical system-evaluating thinking.

The above would require the implementation of the following:

- Higher-Order Cognitive Skills-oriented teaching strategies;
- Active participation of the students in the learning process;
- Fostering of "Question-Asking" and critical, Evaluative thinking;
- *Encouraging group work on homework assignments* & mini-projects;
- Extensive and effective students-teacher feedback mechanisms;
- *No specific course textbook to be assigned, but, rather, selected by the students from a provided list*;
- Providing in-class opportunities to defend and/or 'test' concepts;
- *Students cover/learn material before it is 'covered' by the instructor in class*;
- Lecture, recitation and lab sessions are integrated within the course;
- *Administration of specially designed HOCS- and 'Conceptual' change-oriented exams* [including: e.g., the ESAQ (Examination where the student asks the questions (Zoller, 1994)].

Our practice-oriented research projects, which have been guided by the rationale presented, were based on the assumption, that traditional instructional strategies of teaching and assessment, particularly in science education, are not compatible with the development and fostering of students' HOCS. Similarly, current methods of assessment are not in congruence with the goal of acquisition of HOCS by our students. The findings of our research support the effort to implement HOCS-oriented conceptual teaching strategies and pedagogies in science classrooms at all levels. The paradigm shift from ALG/LOCS teaching to HOCS learning should now be translated into action in science and STES education for sustainability. The time is ripe for this LOCS-to-HOCS/from teaching-to-"know" to-learning-to-"think" shifts. More HOCS-oriented curricula, teaching materials, teaching strategies as well as appropriate assessment tools, need to be developed and implemented if we wish to endow our students with more than just algorithmic capabilities. Such action has the *chance* of developing our students' reasoning and critical thinking ability in the context of both the specific content and processes of science in the STES interfaces contexts, as well as in their question-asking, problem-solving and conceptualization capabilities–so they can become effective citizens.

This is the task ahead for us if *HOCS learning* is the educational goal for our students to attain. A research-based purposed LOCS-to-HOCS paradigm shift in science education is a move in the right direction. Our practice-oriented research efforts contribute to this paradigm shift.

There exist quite many research and practice-evident ways to go "*in line*" with the "*teaching-to-know–to learning-to-think*" for SUSTAINABILITY. Most of them are *HOCS-promoting* teaching strategies and, in accord, examinations types and assessment methodologies (Zoller, 1994). Selected examples (many of them have already been published) of these strategies and methodologies, in the contexts of secondary and (undergraduate) tertiary levels are available and have already been successfully applied in science teaching and assessment, in different multicultural contexts and societies (see references below). Thus, the "translation" of research results and successful science teaching and assessment for sustainability into action, is not only doable, but it *should* be done purposely and persistently.

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