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**ALTERNATIVE ASSESSMENT AS (CRITICAL) MEANS OF FACILITATING
HOCS-PROMOTING TEACHING AND LEARNING IN CHEMISTRY EDUCATION**

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ABSTRACT: The development of students' deep conceptual understanding and higher-order cognitive skills (HOCS) in the context of both the specific content and processes of the science disciplines and the interrelationships of science, technology, environment, and society has become one of the most important goals of contemporary chemistry and science education. However, these distinctions and skills are rarely actually pursued in chemistry teaching. Any progress towards the attainment of these goals requires the application of new teaching and assessment strategies. Examinations as well as other assessment means, must not only be consonant with these goals, but also to meaningfully foster and contribute to their attainment. The crucial issue is how to translate the above into manageable and effective alternative courses and valid HOCS-promoting examinations, the essence of which is the shift from the dominant algorithmic lower-order cognitive skills (LOCS) to the HOCS orientation in chemistry education. With a longitudinal research and teaching program, aiming at the development of students' HOCS, we have developed, implemented and field-tested innovative/alternative assessment methodologies and examination types within chemistry teaching. Selected alternatives (to the existing) assessment means are described and, based on adjunct active research findings, their contribution to the development of students' HOCS in the chemical education context is critically discussed. [*Chem. Educ. Res. Pract. Eur.*: 2001, 2, 9-17]

KEY WORDS: *alternative assessment; higher-order cognitive skills (HOCS); interdisciplinary evaluative thinking; critical thinking; problem solving; decision making; HOCS-promoting examinations and assessment instruments*

INTRODUCTION, RATIONALE, GOALS AND... ACTION

A major driving force in the current effort to reform science education and teaching at all levels is the conviction of many, that it is vital for our students to develop their higher-order cognitive skills (HOCS) capacity in order to effectively function in our modern, complex science and technology-based society. A major purpose of contemporary, future-oriented science, and chemical education accordingly is, therefore, the development of students' reasoning and ability to think critically in the context of both the specific content and processes of traditionally school-taught disciplines and chemistry among them, as well as the processes and interrelationships concerning societal, economical, scientific, technological and culturally-bound issues within real world complex systems, locally and internationally. The implementation of this kind of switch—from the algorithmic/traditional lower-order cognitive skills (LOCS) to the HOCS teaching, learning and, in accord, alternative to the traditional assessment. This is expected to enhance logical, rational, and reflective thinking

which focuses on what to believe and what to do in terms of problem solving-decision making to be followed by responsible action accordingly (Zoller, 1993, 1995, 1997, 2000a).

Although the teaching, learning and assessment/evaluation of HOCS and related capabilities are advocated by many, they are rarely actually pursued, particularly in chemistry teaching. Furthermore, HOCS-oriented teaching strategies and evaluation methods are still in their infancy and not widely-spread. A central issue in chemistry education is, therefore, the 'translation' of this new ideology/superordinate goal into appropriate, relevant, manageable and implementable chemistry and interdisciplinary science courses, teaching strategies and, most important, assessment methodologies in diverse settings at all levels (Zoller, 1993, 1995, 1997, 2000b).

Based on accumulated experience and action research, it is argued, that the implementation of HOCS-oriented teaching and assessment strategies is the key for the attainment of meaningful disciplinary and interdisciplinary "HOCS learning". However, advocating of "what should be done" in chemistry teaching without demonstrating the workability, implementability, effectiveness and goal attainability of "HOCS teaching", via prior in-class experimental research, is irresponsible. Clearly, the LCOS to HOCS shift requires a research-based drastic change in teaching strategies, examination types, methods of assessment of students' performance as well as in students' learning styles. It is our conviction that (a) The development and acquisition of HOCS by our students should be a prime instructional goal in science and chemistry teaching; (b) examinations – as an integral part of the teaching-learning process – should not only be in consonance with the teaching/instructional goals, but should also meaningfully contribute towards the attainment of these goals; (c) students and teachers should not only actively participate in the teaching-learning process, but should become *partners* in the process, in order for the current reform in science and chemistry education to succeed.

The issue of assessment/evaluation directly pertains to how to attain HOCS learning. In designing, administering, and grading examinations, we communicate to the students very clearly both the course philosophy and what we consider to be important. No matter how clearly we think we are speaking to our students in class, it is what we say on exams that matters to them (Aubrecht 1990/1991). This is why examinations as an integral part of the teaching-learning process, should not only be in consonance with the teaching and instructional goals, they should also meaningfully contribute towards these goals (NRC 1996; Zoller 1993, 1994, 1996, 1997). The current HOCS-oriented reform in science requires new HOCS-oriented approaches for testing, assessment, and evaluation that will communicate to the students what counts (see e.g., AAAS 1993; Ben-Chaim and Zoller 1997; Kulm 1990; NRC 1996; Tobias and Raphael 1997; Zoller 1993; 1994). Successfully implemented and researched examples of innovative HOCS-promoting examinations and assessment methodologies are available (e.g., NRC 1996; Tobias and Raphael 1997; Zoller 1993; 1994; 1997; Zoller, Tsaparlis, Fastow, and Lubezky, 1997), and many more should be developed and implemented in the service of chemistry and science education in the near future (Zoller, 2000b).

Closely related is the issue of transfer (i.e., applying learning acquired in one context in another that is previously unfamiliar to the learner) within and across disciplines or domains, which is central to education and learning (Perkins and Solomon, 1989; Solomon and Perkins, 1989). HOCS learning implies interdisciplinary orientation in teaching of the science disciplines, chemistry included, and attention to fundamental/unifying concepts that override ideas and principles (Lederman and Niess, 1997; Zoller, 2000b). It also proposes cross-disciplinary transfer of HOCS as a major criterion for attaining HOCS learning (Zoller, 1993). Thus, HOC0-oriented teaching, assessment and learning in chemistry should be aimed

at enabling students to apply their acquired HOCS in new and/or previously unfamiliar contexts.

Since disciplinary teaching is dominant in contemporary science education, research can determine whether HOCS is transferable within science disciplines. For example, research shows that critical thinking is affected by context and personal experience (Norris and Ennis, 1989), yet, HOCS gains were achieved in classes emphasizing HOCS learning (Zoller, 1993; 1997). However, although thinking strategies in the context of a particular problem in one domain are fully transferable to a new problem in the same domain, they do not transfer as well to an isomorphous problem in a different domain (Zohar 1994). This problem suggests that intentional interdisciplinary HOCS teaching, assessment and learning is the key to cross-domain HOCS transfer (Zoller, 2000b).

We, therefore, contend that interdisciplinary-oriented HOCS learning within the traditional science disciplines would facilitate students' ability to successfully cope with new and/or previously unknown problem-solving situations in different disciplinary and interdisciplinary contexts. Such an interdisciplinary transfer would occur if appropriate teaching and corresponding assessment strategies (proved to be successful by research) are purposely and creatively implemented.

Accordingly, our two-fold goal in the initiation and pursuit of our longitudinal action research program has been the development of (a) the student's reasoning and critical thinking ability in the context of both the specific content and processes of chemistry and those of the interdisciplinary science-technology-environment-society (S-T-E-S) interfaces; and (b) their problem-solving decision-making capacity for so they can be effective citizens (Zoller, 1990). This is guided by the ultimate educational ideal of the *educated person*: one who has the ability to be engaged in *higher-order skills-based forms of inquiry* . (i.e. PS, DM, creative thinking) required both in the study of the disciplines and in dealing with characteristically interdisciplinary everyday life situations; the knowledge base relevant to these situations, the ability to select and apply the *relevant* information and skills guided by reflective, responsible attitudes; and the *motivation and self-confidence* to act accordingly and to take responsibility (Zoller, 1993; 1995; 1997, 2000a,b)

In our previous related studies we have found that:

1. Both college and high school students prefer examinations which emphasize understanding and analysis rather than tests of plain knowledge and rote learning and that time duration of these *open-book* type examinations be virtually unlimited (Zoller, Ben-Chaim & Kamm, 1996; Ben-Chaim & Zoller, 1997).
2. Despite awareness of these students' exam-type preferences, science teachers persist in administering their own "pet"-type examinations (Zoller, Ben-Chaim & Kamm, 1996).
3. Students' success on algorithmic exam questions do not imply their success on either LOCS or conceptual questions, suggesting that:
4. Success in solving algorithmic (conventional) test problems (exercises!) does not mean conceptual understanding in chemistry (Zoller et al., 1995).

Based on the above rationale, convictions, goals and research findings, which guided our chemistry teaching and research, we have re-formulated our specific, simultaneous, teaching and research objectives as follows:

1. To assess students' performance on algorithmic, LOCS and HOCS exam questions and to look for correlations (if any) between their achievements on these categories across different populations.

2. To explore the possibility of identifying HOCS and LOCS students and their distribution in different populations via “post factum” analysis of their performance on chemistry examinations of different types and level which contain both “HOCS” and “LOCS questions” as well as the *preferences* of these two types of students with respect to HOCS and LOCS exam questions.
3. To assess science students’ capability and confidence in self- and peer’s assessment of both HOCS- and LOCS-oriented examinations.
4. To develop and implement new instruments and strategies for the assessment of students’ HOCS, within STES-oriented chemistry and science teaching.

The essence of selected relevant research projects, their findings, conclusions and implications, as well as of innovative, alternative assessment means for HOCS, which were successfully applied within ongoing chemistry teaching follows.

RESEARCH-BASED ALTERNATIVE ASSESSMENT FOR HOCS PROMOTION

(1) ALGORITHMIC, LOCS AND HOCS (CHEMISTRY) EXAM QUESTIONS: PERFORMANCE AND ATTITUDE OF COLLEGE STUDENTS (Zoller, Dori & Lubezky, 2000):

The performance of freshmen biology, physics-mathematics and chemistry majors as well as pre- and in-service chemistry teachers in two Israeli universities on algorithmic (ALG), lower-order cognitive skills (LOCS), and higher-order cognitive skills (HOCS) chemistry exam questions was studied. Thus, college students’ responses to the specially designed ALG, LOCS and HOCS chemistry exam questions were scored and analysed for differences and correlation between the performance means within and across universities by the questions’ category. This was followed by a combined student interview - ‘speaking aloud’ problem solving session for assessing the thinking processes involved in solving these types of questions and the students’ attitudes towards them.

The main findings were: (1) students in both Universities performed consistently on each of the three categories in the order of ALG > LOCS > HOCS (see Table 1); their “ideological” preference was HOCS > algorithmic/LOCS (are referred to as ‘computational questions’), but their pragmatic preference was the reverse. (2) Success on algorithmic/LOCS does not imply success on HOCS questions; algorithmic questions constitute a category on its

TABLE 1. Means of students’ performance on examination questions by question type and university.

Question type	University	N	ALG		LOCS		HOCS	
			Q1	Q2	Q3	Q4	Q5	Q6
	Haifa	64	87.2 (SD=20)		68.2 ^a (SD=32)		55.9 (SD=29)	
	Technion	33	88.0 (SD=21)		69.9 ^b (SD=29)		64.4 (SD=31)	
	Mean Total	97	87.8 (SD=20)		69.4 (SD=31)		58.7 (SD=30)	

own as far as students success in solving them is concerned (See also Zoller et al., 1995). Our studies and their results support the effort being made, worldwide, to integrate HOCS-fostering teaching and alternative assessment strategies and to develop HOCS-oriented STES-type courses within chemistry science and education.

(2) THE FREE CHOICE TAKE-HOME LOCS AND HOCS EXAMINATION (Zoller, 1995; Zoller and Tsaparlis, 2001).

This study involved a mid-term take-home examination, within a general chemistry course for freshman biology majors (prospective science teachers), consisted of a set of ten questions categorized as algorithmic (A), LOCS (L), HOCS (H), or mixed (A/L, A/H, L/A, A/L/H, etc.). The students were asked to choose just *two* questions (out of the ten) as they wish, to work them out at home, taking their time and using any material they may need, and to submit their ‘final product’ – as a substitute for an ordinary mid-term examination (in chemistry) – for grading.

The types of questions, on a take home-type chemistry exam (Tsaparlis & Zoller, 1995), selected by students vs their *total* score on this exam are delineated in Table 2 (Zoller, 1995). It is *noteworthy* that the highest scored students selected only algorithmic and *LOCS* questions to respond to. Apparently, the drive to succeed on exams, at all cost, in view of the consequences involved, is the decisive factor which determines the preference of question-type on the part of students within the existing realism of constraints of our educational system.

TABLE 2. *Students’ performance versus the LOCS/HOCS distribution of their selected take-home exam questions (N=22; F=1, M=6).*

Score ^(a)	Number (of students)	(%)	Type of Questions ^(b)	Level ^(c)
96-100	4	(18)	A&L	LOCS
91-95	6 {	2	A&L	LOCS
		2	A&A/H	LCOS & MOCS
		2	A&L&L/H or A/L/H	LOCS & MOCS
80-90	4 {	2	A&A/L/H or A/H	LCOS & MOCS
		2	A/L/H/ & A/H or L/H	MOCS
60-79	5 {	1	A & A/L	LOCS
		1	A/L & A/L/H	LOCS & MOCS
		3	A/L/H & A/H	MOCS
			A/L/H or A/H & H	MOCS & HOCS
<55	3	(14)	A or L or A/L & A/L/H or A/H	MOCS & LOCS

^aScale: 0-100; ^bAlgorithmic-A; Low-Level-L, Higher-Order-H; ^cLOCS: Including A, L & A/L as single items within the question; HOCS: Including A/H, L/H, A/L/H, and H as single items within the question; MOCS: (Mixed order cognitive skills): Including both HOCS and HOCS items within the question.

(3) STUDENTS' SELF ASSESSMENT IN CHEMISTRY EXAMINATIONS REQUIRING HIGHER- AND LOWER-ORDER COGNITIVE SKILLS (Zoller, Fastow, Lubezky and Tsaparlis, 1999):

Within this project we explored the possibility of involving students in HOCS-promoting processes within chemical teaching via self-assessment and self-grading of HOCS-oriented chemistry examinations.

Our research questions were:

1. Can students in a college chemistry course perform self-assessment?
2. Is their assessment compatible with that of their professors?
3. Are the students confident in doing this self-assessment?

The research design was based on the following selected exam questions, which were graded by both students and their professors in freshman general chemistry courses in Israel and Greece:

One of the best ways of checking the purity of PCl_3 which is used in the manufacture of saccharin, is to compare the mass spectrum of a sample with that of pure PCl_3 . Given: that chlorine has two naturally occurring isotopes (^{35}Cl and ^{37}Cl , relative abundance – 75:25%, respectively), whereas phosphorus has just one (^{31}P).

- Q1. In your opinion, is the given relative abundance for the chlorine atom (75:25%) relevant to the method here presented for checking the purity of PCl_4 ? *Explain.*
- Q2. *How many* molecular peaks and which *specific masses* do you expect to find in the mass spectrum of *pure* PCl_3 ? Is the emphasis on *pure* important? *Explain.*
- Q3. Do you expect the *number of peaks* in the mass spectrum of pure PBr_3 , to be the same as that of pure PCl_3 ? *Explain.*
- Q4. Do 10 grams of PCl_3 contain more, the same, or fewer *atoms of chlorine* than the *number of bromine atoms* in 10 grams of PBr_3 ? If you think that the number is the same, then explain *why*; if not, calculate the *weight* of PBr_3 which contains the same number of bromine atoms as the number of chlorine atoms in 10 grams of PCl_3 .

The first parts of Q2, Q3, and Q4 are considered LOCS; Q1, Q5, and the last part of Q2-Q4 are HOCS.

The results of the Israeli students' evaluation of their capability and confidence in self-assessment and assessment of peers indicate, that they believe that "to a reasonable extent" they are *capable* of self-assessment and feel *confident* in this process ($\bar{x} = 2.95$ on a 4-1 scale). Similarly, they believe in their capability of assessing their peers and have confidence in doing so ($\bar{x} = 2.6$). These findings are rather encouraging.

Selected results comparing the students' self-grading of their first-semester midterm take-home exam with the grading of the same chemistry examinations by their professors are given in Table 3. The main findings are, that the gaps between the students' self-grading and their professor's grading of LOCS questions (e.g., Q3) are fairly small and statistically nonsignificant, whereas the gaps in the grading of HOCS questions (e.g., Q1) are relatively large. We conclude that students' self-assessment of chemistry exam questions requiring LCOS is compatible with that of their professors, but that requiring HOCS is not. These results suggest, that the more familiar students are with a problem, or the deeper their conceptual understanding of the problem is, the better are both their performance and the matching of their self-assessment with the assessment of their professors.

TABLE 3. Students' and professors' grading of questions on a midterm chemistry exam.

Country	N	Question												Overall	
		Q1		Q2		Q3		Q4		Q5		S	P	S	P
		S	P	S	P	S	P	S	P	S	P				
		Δ		Δ		Δ		Δ		Δ		Δ			
Israel	24	80.2	61.1	89.0	84.4	89.6	92.9	96.8	93.3	88.3	77.3	89.4	81.7		
		19.1		4.5		-3.3		3.5		11.0		7.7			
Israel	28	82.5	64.8	87.8	87.0	87.4	82.2	93.8	85.0	79.4	65.9	85.5	77.0		
		17.7		0.8		5.2		8.8		13.5		8.5			
Greece	56	60.8	37.6	57.9	26.6	62.2	61.1	92.2	86.3	76.6	48.4	64.1	47.7		
		23.2		31.3		1.1		5.9		28.2		16.4			

NOTE: Grading was from 0 to 100. S represents mean self-grading score of students' grade and P represents the professor's mean grade of the students. A positive Δ (S-P) indicates an overestimation by students compared with professors; the single negative Δ indicates an underestimation.

INNOVATIVE ALTERNATIVE ASSESSMENT

Selected HOCS-promoting alternative (to the traditional LOCS-type) examinations, that have been developed and successfully implemented in chemistry teaching, e.g., the Eclectic, and the Individualized Eclectic Examinations (EE and IEE) (Zoller, 1993; 1997), the Examination where the Students ask the Questions (ESAQ) (Zoller, 1994) – have already been presented and discussed in this journal (Zoller, 2000a). Their contribution to evaluative thinking and HOCS learning is self-explanatory. Yet, several major components of HOCS, such as problem- (not exercise) solving, critical thinking, system (lateral) thinking and decision-making are not being assessed routinely in most science and, needless to say, chemistry courses. To this end, we have developed and validated appropriate assessment instruments one illustrative example of which – with respect to the *decision-making* capacity – is presented below (Zoller and Gross, 2000). It constitutes part of the multicomponent HOCS Evaluation Questionnaire (HEQ) developed by us for the assessment of HOCS, primarily in STES-oriented courses (Zoller et al., 2001).

1. 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.

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 that 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 new criteria that guided you (or will guide you) in your decision concerning the most desirable alternative.
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 in your answer to questions 1, 2, 3 and explain.

CONCLUSIONS/SUMMARY.... AND RECOMMENDATIONS

- (a) Examinations, particularly those containing both HOCS and LOCS questions, can be effectively used to identify “HOCS”- and “LOCS-students”.
- (b) There is no correlation between students’ “HOCS” - and “LOCS performance”; Algorithmic > LOCS > Conceptual > HOCS.
- (c) Given a free choice, “LOCS questions” are preferred on “HOCS questions” by students under test situations, apparently due to their governing “student proof” attitude towards examinations.
- (d) In their self-assessment students overestimate their performance on HOCS-questions whereas their grading matches with that of their teachers on LOCS questions.
- (e) Self-assessment of good students is in excellent agreement with that of their professors on both categories. Thus, students’ HOCS and their progress in chemistry learning can be assessed, the need for remedial teaching strategies can be deduced from the results of appropriately designed and implemented alternative HOCS-oriented examinations, and the latter can be effectively used for identifying students HOCS capabilities.

We have demonstrated the effective use of HOCS-oriented teaching, in accord, assessment strategies and, most important, the attainability of HOCS learning. Persistent and purposeful *HOCS-oriented* chemistry teaching and learning work needs to be done. Since the development of students’ HOCS capability is a major objective in the reform of science and chemistry education, HOCS-oriented teaching, assessment and *learning* strategies should become the focus of the teaching-learning process.

The answer to the “million dollar” question — “Are we getting it right?” — is not yet possible because of the limited research available. Based on the accumulated data and evaluation studies conducted worldwide thus far, one can only respond to the question, “*Can* we get it right?” The answer to this question is, “Yes, we can”, provided appropriate measures are persistently and purposely taken within science teaching.

Many of us believe that targeting our courses and teaching at HOCS learning in the next millennium is timely and crucial for ensuring our future well-being. Contemporary educational reform in science education certainly has generated momentum and action worldwide. The road to achieving HOCS learning is rocky, but within reach, since the means – appropriate HOCS-promoting teaching and assessment strategies – are available. It is up to each one of us, within his or her particular constraints, to make it happen. So let’s get to work.

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