Perspective

Evaluation of higher *vs.* lower-order cognitive skills-type examinations in chemistry: implications for university in-class assessment and examinations

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The absence of sufficient, convincing, research-based documentation is often quoted as an argument against any change in the currently dominant lower-order cognitive skills (LOCS)-type examinations. Our aim with this paper is the fostering of higher-order cognitive skills (HOCS) learning, based on three relevant research studies: two conducted in Greece, and one in Israel. A different pattern of students' performance was revealed on examination questions requiring HOCS compared with that on questions requiring LOCS. A high performance on the latter does not necessarily guarantee a high performance on the former, and the reverse may also be the case. A 'high-stake' examination, used for entry into higher education in Greece, was found to select the best LOCS-performing students! Alternative forms of examination, such as the 'take-home exam', proved to be useful mainly for the enhancement of university students' active participation in courses, their self-directed, independent study, and the cultivation of their HOCS through the inclusion of questions requiring HOCS, dealing with material not covered in class. In a related Israeli study, conducted within an introductory freshman general and inorganic chemistry course, it was found that, given a free choice between HOCS- and LOCS-type questions, the top performing students preferred to answer questions requiring LOCS, in spite of proclaiming their preference of those requiring HOCS.

Introduction

The almost compulsive need for extensive testing and assessment in science education within contemporary educational systems at all levels may result in stagnation, if not regression, in attaining the newly emerging educational-instructional goals worldwide.[1] Yet, the absence of sufficient, convincing, relevant, research-based findings is often quoted as a strong argument against any change in the currently dominant lower-order cognitive skills-type examinations.[2] In this work, we briefly describe and critically analyze research work which examines the two types (lower- and higher-) cognitive skills (LOCS and HOCS), and has direct bearing on the issue at point. Three relevant studies, the first two conducted in Greece, and the third in Israel, are reviewed and discussed further for this purpose. These are:

1. A comparison of one examination, the Panhellenic Chemistry Competition (PCC), analyzed for LOCS vs. HOCS-type questions, with a second examination, the General Examination (GE), used for entrance into higher education in Greece.[3] In a directly connected study, the student performance patterns in science/chemistry examinations which require HOCS or LOCS were examined.[4]
2. The use of take-home examinations to promote students' participation, collaboration and the development of their HOCS.[5]
3. A study focusing on students' LOCS/HOCS declared preference, compared with their actual performance within a freshman introductory general and inorganic chemistry course at an Israeli university, targeted at promoting HOCS-learning.[6, 7]

The work here presented is complementary to related research studies,[4, 6-10] and is guided by the following rationale:

- Examinations should not only be consistent with the teaching/instructional goals, but also, meaningfully, contribute towards their attainment.[2, 6, 8, 11, 12]
- The development/acquisition of HOCS by our students should be a major instructional goal in both disciplinary (e.g., chemistry) and interdisciplinary science teaching at all levels.[2, 4, 8-15]

- Appropriately designed HOCS-oriented examinations in science/chemistry teaching should be used to (a) foster and develop students' HOCS capabilities, and targeted at HOCS learning;[2] (b) reveal their misconceptions (followed by their remediation) and distinguish between students' misconceptions, misunderstandings and 'no conceptions'[8] for appropriate teaching-learning strategies to be applied accordingly in line with 'HOCS *learning*';[2, 11, 14] (c) foster a shift from concentrating on the dominant algorithmic exercise solving ability to meaningful problem solving, requiring conceptual understanding[14-16] /'HOCS *learning*';[11-15] and (d) identify (not label), within context, students who are fitting or close to the HOCS-type (henceforth HOCS-students), and students who are fitting or close to the LOCS-type (henceforth LOCS-students), in science courses for improving course-teaching and assessment strategies, regardless of whether the related teaching was LOCS- or HOCS-oriented.[4-11] [A word of caution: as with any human quality, the distinction between HOCS and LOCS cannot be dichotomous; instead, HOCS and LOCS are 'classified' within the edges of a continuum. The categorization we use here is just for the purpose of the study, not for labeling students.]

Based on selected relevant research results and the related evolving implications for science/chemistry teaching, this paper is directed at the fostering of HOCS learning. There are chemistry teachers who subscribe to the view that mastery of computational, LOCS-type exercises (traditionally referred to as 'problems') is 'equivalent' to conceptual understanding of chemistry. A series of studies and articles have demonstrated that this wide-spread notion is unfounded.[15-27] Of particular relevant interest is the connection of performance in algorithmic and conceptual items to psychometric variables.[28-31] Since this paper is about assessment and examinations, particularly the HOCS-type, these will constitute its focus.

LOCS and HOCS examination items

LOCS and HOCS examination items (an item being a question, or a group of questions, or an exercise or a problem, or a 'scenario' to relate to) are operationally defined as follows:[4, 15]

> *LOCS items:* These are knowledge questions that require simple recall of information or a simple application of known theory or knowledge to familiar situations and context. They can also include the so called 'problems', mostly computational exercises, solvable by the application of taught/recalled/known algorithms, not necessarily understood by the 'solver', which are already familiar to the learner through previous specific directives, or long-term practice, or both.
>
> *HOCS items:* These are quantitative or qualitative, ill-defined/structured, or open-ended questions, mostly unfamiliar to the student, which require for their 'solution' much more than just knowledge and/or application of known algorithms; they may require analysis, synthesis, system thinking, decision making, problem-solving capabilities, but mostly the making of connections, and critical evaluative thinking.[2, 15, 32] This includes the application of known theory or knowledge to unfamiliar situations or situations with an unusual element or dimension.[33] In this respect, HOCS extend far beyond the skills of analysis, synthesis, and evaluation to those of critical-, system (lateral) evaluative thinking, requiring the synergistic interaction/integration of these and related skills in different situations and contexts.[2, 14, 32]

Examples of HOCS and LOCS questions in chemistry examinations are provided later in this paper, as well as in previous publications.[4, 8, 10, 14-16]

Greek Study I: The Use of One Examination for the Evaluation of Another Examination

In this study, we compared the General Examination (GE) with the Panhellenic Chemistry Competition (PCC) exam, both held in Greece in 1991 for high school graduates (N = 1352). The second examination offered a 'golden' opportunity to carry out such an evaluation, by being used as a frame of reference or measuring stick. The two examinations have quite different features: PCC is informal, and places the emphasis on items that require HOCS;[11] GE is formal, and consists of questions that require simple recall of knowledge and algorithmic exercise solving; that is, of questions that require just LOCS.

The GE was targeted at secondary education graduates (age 17-18) who competed for admission to higher education in Greek institutions. The chemistry section consisted of four major items. Two of these were knowledge questions (LOCS-type), the answers to which could be found in the standard chemistry textbook, with no need for any cognitive processing other than simple recall. The other two items were algorithmic computational 'problems'. Because of the severe competition, students preparing for the exam study hard, solving a large number of computational 'problems'. In this way, problems are treated by the application of

Table 1. *Student performance (means; standard deviations in parentheses) in the Panhellenic Chemistry Competition (PCC), the Chemistry General Examination (GE), and on the HOCS and LOCS components of the PCC.* [4]

Group/Subgroup		*N*	PCC	PCC_{HOCS}	PCC_{LOCS}	GE
1.	All students	1352	24.4 (18.6)	-	-	-
2.	Students with marks ≥ 50 in PCC	146	61.8 (8.8)	54.3 (12.1)	72.2 (13.4)	92.5 (6.9)
3.	Students with marks ≥ 68 in PCC	42	73.3 (4.4)	66.8 (6.6)	82.2 (9.8)	95.4 (5.9)
4.	Students with marks ≥ 35 in PCC and marks 98.8-100 in GE	40	62.9 (13.2)	-	-	99.3 (0.5)
5.	Students with 35, 36, or 37 in PCC*	43	35.7 (0.5)	-	-	84.1 (10.9)
6.	Students with marks ≥ 70 in PCC_{HOCS}	16	74.6 (6.4)	74.1 (3.1)	75.3 (14.6)	94.4 (6.0)
7.	Students with marks ≥ 90 in PCC_{LOCS}	16	73.9 (7.1)	59.8 (11.5)	93.4 (2.3)	94.7 (4.7)

* Note that about half (21) of these students had a very high mean performance in GE (93.5).

known and well-practiced algorithms, thus turning them into 'exercises'. Operationally, we categorized all GE questions as questions that required LOCS for their solution, i.e., LOCS items. This is in line with the perception of the GE by all involved (State, news media, teachers, parents and students) as a test that requires just rote learning, not critical thinking or other related HOCS.

The Panhellenic Chemistry Competition (PCC), on the other hand, is aimed at the annual selection of the students who represent Greece in the International Chemistry Olympics. Although the chemistry dealt with in the PCC is, as a rule, known to the students from their high school chemistry courses, a considerable number of questions require the application of theory, known or acquired by the students, to novel situations, i.e., HOCS. Consequently, we categorized the questions of the PCC into HOCS-type questions (for which we will use the notation PCC_{HOCS}) and LOCS-type questions (for which we will use the notation PCC_{LOCS}). The 1991 PCC examination consisted of 22 (58%) HOCS and 16 (42%) LOCS questions. Table 1 provides the summary of student performance data for the two examinations.[4]

Discriminating power of the two examinations

A main feature of the PCC, which is due to its more demanding questions, with less time available to answer them, is its capacity to effectively classify 'good' students, that is, to discriminate between the 'good' and the 'very good' ones. The values of the standard deviations (SD) demonstrate this power. Thus, for the 42 best performing students on the PCC, the SDs are 4.4 for the PCC and 5.9 for the GE. On the other hand, for the 40 best students on the GE, the corresponding SDs are 13.2 and 0.5 respectively. As we move down the scale of performance, the PCC is losing this discriminating power. In contrast, the GE, although failed to discriminate among 'good' students, had a sufficiently good discriminating power as we move to the lower performance levels. Thus, the 43 students of our study, with the lowest marks in PCC - 35, 36 and 37 (out of 100) - had a SD of 0.5 on the PCC and 10.9 on the GE. It follows that performance on the PCC is a poor predictor of performance on the GE.

Student performance patterns on questions requiring HOCS and LOCS

By comparing the performances on the PCC_{HOCS} and PCC_{LOCS} items of the 146 students who achieved at least the 50% level in the PCC, we found that the performance on the items requiring LOCS was much higher (17.9 points on a 0-100 scale) than that on the items requiring HOCS. This finding could have been expected and was corroborated in other related studies.[7, 15, 16] Indeed, the correlation between performance on PCC_{LOCS} and GE was higher (Spearman rho = 0.32) than that (0.25) between PCC_{HOCS} and GE (Table 2).

Table 2. *Spearman correlation matrix for the Panhellenic Chemistry Competition (PCC),* the Chemistry General Examination (GE), and the HOCS and LOCS components of the PCC.* [4]

	PCC	GE	PCC_{HOCS}	PCC_{LOCS}
PCC	1			
GE	0.39	1		
PCC_{HOCS}	0.77	0.25	1	
PCC_{LOCS}	0.59	0.32	-0.01	1

*Students with marks ≥ 50% in the PCC (*N* = 146).

Surprisingly, no correlation (Spearman rho = -0.01) was found between students' scores on PCC_{HOCS} and PCC_{LOCS}. The fact that students who did very well on PCC_{HOCS} (entry 6 in Table 1) did not score higher on PCC_{LOCS}, explains this lack of correlation. This fact is surprising in view of the expectation that HOCS students should, in principle, be able to deal successfully with items requiring just LOCS. According to Bloom's taxonomy, the possession of LOCS is taken for granted as a prerequisite for having the HOCS capacity, thus assuming that we can have LOCS-only students but not HOCS-only students. On the other hand, the overall correlation between PCC and PCC_{LOCS} (0.59 see Table 2) was found to be statistically significant, apparently for the students who must have taken the PCC with very good preparation.

A possible explanation for the lack of correlation between students' scores on PCC_{HOCS} and PCC_{LOCS} is the extent of the students' pre-examination preparation; that is, practically speaking, many PCC participating students failed to prepare for it. One cannot exclude, however, the involvement of affective factors, such as motivation and personal preference for particular types of questions[7] as being important contributors to the above finding.

What is the effect of the extent of pre-exam preparation on performance, and what are the implications of our relevant findings for in-class assessment? Clearly, students with varying amount of preparation have taken the PCC exam. Our findings suggest that the difference in preparation has affected the performance on the questions requiring LOCS (PCC_{LOCS}) but not necessarily on the questions requiring HOCS (PCC_{HOCS}). Students who did poorly on the PCC_{LOCS} but did relatively well on the PCC_{HOCS} have probably had only a little preparation for the PCC. That the lack of, or an inadequate preparation is, indeed, the reason for the latter 'no difference' can also be inferred from essentially the same mean PCC_{LOCS} mark of these 'HOCS students' as that of the whole 146 student sample.

These results suggest that both HOCS- and LOCS-type questions ought to be used in class assessment. This will not only promote HOCS learning,[2, 12, 32] but also identify and distinguish between HOCS- and LOCS-type students. This approach can be applied in both formative and summary evaluations, as well as in designing the course teaching and remediation.

We conclude, that the PCC_{HOCS} and PCC_{LOCS} parts of the PCC measure quite different skills, i.e., HOCS versus LOCS. This can also be deduced directly through an appropriate statistical factor analysis in which the performances of the 146-student sample on the PCC, the PCC_{HOCS} and PCC_{LOCS} parts of the PCC as well as on the GE were taken as entry data.[4] Two factors were thus extracted, one loading on PCC and PCC_{HOCS}, the second on GE, PCC and PCC_{LOCS}. We find that our conclusion regarding the difference between HOCS and LOCS is supported by this analysis. (Note that factor analysis considers the correlation of a number of observed variables to be a result of their sharing of common sources or *factors*, and not as a result of one being a direct cause of the others.)

Greek study II: the take-home, open-book examination as a means to promote students' participation, collaboration and HOCS

Many university science and chemistry educators are concerned about the poor lecture attendances by students in university lecture-based courses. There are countries, such as Greece, where it is not mandatory for students in universities to attend lectures. As a result, attendance at lectures is low, and students do not participate actively in the learning process. However, these students attend examinations, often without adequate preparation, their preparation being largely textbooks-based. What is worse is that there is a little chance that they will develop their HOCS.

One easy means that may be very effective in increasing student participation and collaboration in the learning process, particularly with respect to their HOCS development, is the take-home, open-book examination.[34] This 'method' has been applied in Greece and the results were very encouraging.[35] The participation and involvement of the students was widespread and enthusiastic.

Table 3. Students' (N = 85) mean performance (standard deviations in parentheses) in the take-home examination.[35]

	Questions based on material taught in class			Questions outside of material taught in class		
	LOCS in knowledge (3 questions)	LOCS in application (2 questions)	Total (5 questions)	HOCS (4 questions)	LOCS in exercise (1 question)	Total (5 questions)
M (*SD*)	88.0 (6.1)	74.0 (15.5)	82.4 (7.4)	35.2 (20.6)	81.7 (28.9)	44.5 (19.9)

Almost all students handed in their papers on time, after dealing, seriously and extensively, with all the questions posed. Most papers were carefully worked out and nicely written.

Table 3 summarizes the students' performance on the take-home examination. Students performed very well on the knowledge and application questions that could be found directly in, or with the aid of the course textbook. They performed equally well on a question that required LOCS (a stoichiometric calculation: Do 10 g of PCl_3 contain more, the same, or fewer atoms of chlorine than the number of bromine atoms in 10 g of PBr_3?) However, their performance dropped dramatically on the HOCS questions that dealt with material outside that taught or discussed in class, in spite of their use of several textbooks and the intra-student collaboration that took place. An example of such a question is given below (for more examples, see Zoller et al. [10]):

> One of the best ways of checking the purity of PCl_3, which is used in the manufacture of saccharine, 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 isotopic abundance ~ 75:25, respectively), whereas phosphorus has just one (^{31}P), in your opinion, is the given relative isotopic abundance for the chlorine atom (75:25) relevant to the method here presented for checking the purity of PCl_3? [This question is not only different in kind, in that it clearly requires HOCS, but also is a much more difficult question than the previous, LOCS, one. It is hardly surprising that the marks were lower.]

Table 4 shows student performance on the January 1995 end-of-semester examination, as well as previous years' results in the same course, taught by the same instructor. Although no direct inference could be made concerning the effect of the take-home exam procedures on the students' performance, clearly it had a substantial effect on student participation in the exam: the latter climbed to 94% in the year of the take-home exams, compared with 76% and 80% in the two previous years. (Taking an exam is optional in Greece.)

The Israeli study: students' performance versus selected LOCS/HOCS questions

A study was conducted within a freshman introductory general and inorganic chemistry course for biology majors (N = 22) at an Israeli university that compared the students' stated preferences regarding LOCS- and HOCS-type questions with their actual choices made in examinations.[7] The study involved a mid-term take-home examination which consisted of a set of ten questions categorized as algorithmic (A), LOCS (L), HOCS (H), or mixed-order (MOCS) [i.e. consisting of algorithmic and LOCS parts (A/L), algorithmic and HOCS parts (A/H), algorithmic and LOCS and HOCS parts (A/L/H), etc.]. The students, who had been exposed to HOCS-promoting teaching for half a term,[11] were asked to choose just two questions (out of ten); to work them out at home on their own while taking their time; to use any material they might need; and to submit their final answers for grading as a substitute for an ordinary mid-term examination. This meant that the students could choose (if so they wished) two algorithmic or LOCS questions only, and avoid HOCS questions altogether. Questions 2, 3 and 5 - categorized by a panel of experts as algorithmic (A), LOCS (L), and HOCS (H) respectively - are given below as representative examples:

Question 2 (A). When $CaCO_3$ is heated, CaO and CO_2 are obtained. What will be the weight of the remaining solid mixture if 25 grams of $CaCO_3$ are heated in an open container until half of the $CaCO_3$ is decomposed?

Question 3 (L). Which is the oxidizing agent and which is the reducing agent in the following reactions?

i. $F_2 + 2Cl^- \rightarrow 2F^- + Cl_2$
ii. $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
iii. $2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$
iv. $H^+ + OH^- \rightarrow H_2O$

Table 4. Freshman students' performance on the end-of-semester formal elementary physical chemistry examination.[35]

Year	1992	1993	1994	1995
N [a]	43	61	64	75
Participation [b]	54%	76%	80%	94%
Successful among all exam participants	44.2%	65.6%	46.9%	56.0%
Successful among all freshman students	24.0%	50.0%	37.5%	52.5%

[a] Freshmen only who took the exams.
[b] An estimate of student participation in each exam, based on an average total of 80 students per year.

Question 5 (H). The following are three balanced reactions and yet, the chances for the first two to actually take place are very small, whereas the third would occur under appropriate conditions. Why? Rationalize!

i. $Br_2 + 2NaCl \rightleftharpoons Cl_2 + 2NaBr$

ii. $K_2SO_4 + 2H_2O \rightleftharpoons 2KOH + H_2SO_4$

iii. $Cl_2 + Br_2 \rightleftharpoons 2BrCl$

We hypothesized (or hoped...), that the good ‘HOCS-students’ in the class—after being exposed to ‘HOCS-teaching’[12] —would prefer HOCS-type questions, given a free choice on examination situations. The students’ performance distribution, versus their selected two out of ten take-home exam questions (LOCS, or HOCS, or ‘mixed’) to respond to is given in Table 5.[7, 36]

The top performing students, six out of 22 (27%), preferred to select and respond to LOCS-type questions. This clear-cut selection of only LOCS-type questions by these students can easily be rationalized by the ‘student-proof’ approach to grading in examination situations; that is, students prefer to choose what they perceive to be the *easiest* possible way to get a high grade without taking any risk, regardless of their preference of HOCS/conceptual understanding-type questions, and/or whether or not a much more *challenging* (and meaningful) alternative is available. Since these students could get away without the need to respond to HOCS (or even MOCS) questions, we do not know (based on the given results only) if they were ‘LOCS’ or ‘HOCS’ (or ‘MOCS’) students. The pattern change in the ‘profile’ of the questions selected by the freshman students from top to bottom in the LEVEL column (i.e., LOCS → LOCS plus MOCS → MOCS ... → MOCS plus HOCS) suggests that the HOCS-oriented instruction during the two months period preceding the examination was not sufficient to change students’ ‘exam-attitudes/behavior’ as far as the hoped for shift in preference from LOCS to HOCS learning is concerned.

Summary, Conclusions and Implications

It was found in the Greek Study I, that there is a different pattern of students’ performance on examination questions requiring HOCS, compared with that on questions requiring LOCS. A high performance on the latter does not necessarily guarantee a high performance on the former. On the other hand, many ‘HOCS students’ in our study performed no better on the supposedly easier questions requiring just LOCS, compared with their performance on questions requiring HOCS. Based on the analysis of the data, we have attributed this finding to insufficient pre-examination preparation/study. Alternative interpretations, such as low interest in, motivation by, and/or disposition towards the traditional rote-type and algorithmic examination items, cannot be excluded. Nevertheless, our results may suggest that the ‘linearity’ assumed/implied in Bloom’s taxonomy, that the possession of LOCS is taken for granted as a prerequisite for having the HOCS capacity is questionable, at least with respect to a certain segment of the student body.

Table 5. Israeli students’ performance distribution versus their selected LOCS, HOCS, and mixed-order (MOCS) questions.[36]

Score[a]	Number of students		%	Type of question[b]	Level[c]
96-100	4		18.2	A & L	LOCS
91-95	6	2	9.1	A & L	LOCS
		2	9.1	A & A/H	LOCS & MOCS
		2	9.1	A & L & L/H or A/L/H	LOCS & MOCS
80-90	4	2	9.1	A & A/L/H or A/H	LOCS & MOCS
		2	9.1	A/L/H & A/H or L/H	MOCS
60-79	5	1	4.5	A & A/L	LOCS
		1	4.5	A/L & A/L/H	LOCS & MOCS
		3	13.6	A/L/H & A/H A/L/H or A/H & H	MOCS MOCS & HOCS
<55	3		13.6	A or L or A/L & A/L/H or A/H	MOCS & HOCS

(a) Scale: 0-100

(b) Algorithmic – A; lower-order – L, higher-order – H

(c) LOCS: 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 LOCS within the question.

A major finding was that a formal examination that is decisive for students' future, such as the General Examination in chemistry (GE) of Greece, aiming at selecting the best students for higher education, was emphasizing LOCS. Consequently, it achieved the selection of the best LOCS-performing students! It is impossible to say, however, whether it concurrently succeeded in selecting, at least partly, the students who have had already acquired the HOCS capability.

The prevailing LOCS orientation in contemporary science and chemistry teaching versus the low prevalence of fostering students' development of HOCS structures are, most probably, responsible for the much lower performance of students on HOCS- than on LOCS-type examinations. One should also take into account the possibility that questions of the two kinds (requiring HOCS or LOCS) may differ in their degree of difficulty.

It has been suggested,[3] that there should be a scaling up of the difficulty and skills required of the questions set on the GE, in order to increase its discriminating power with respect to the very 'good' students. (By 'good' students we are implying those who have developed, at least in part, a HOCS capability.) At the same time, the good discriminating power of the GE with respect to the less able or less prepared students should be maintained. The above suggestion has, in part, been implemented in recent years in two ways: (a) initially, by increasing the complexity of the algorithmic GE problems, making them draw on more than one area of chemistry. (The increase in complexity was well received by the teachers, the media, and the Association of Greek Chemists.) (b) By a radical change from year 2000 onwards in the type of the questions, to include now a number of both open and objective (multiple-choice) type questions, some of which require conceptual understanding (but less often HOCS capability) to be demonstrated.

Greek Study II showed that alternative forms of examination, such as the take-home one, can be useful, particularly in encouraging students' active participation in the course, and their self-regulating, independent study. They provide the instructor with the opportunity to extend the range of topics beyond those that are formally covered in the lectures. The take-home exam provides students with practice of working out exam questions on their own, and provides a feedback mechanism with respect to students' progress and difficulties. It enforces students to consult other texts apart from the course textbook. Also, it encourages collaboration among students within the learning process. Last, but not least—though we have not offered evidence—it is hoped that the HOCS-oriented parts in these exams will cultivate and foster students' HOCS.

The most significant result of the Israeli Study was that the top performing students, given a choice between HOCS- and LOCS-type questions, preferred to select and respond to the LOCS-type ones, suggesting that a short-term HOCS-oriented instruction is not sufficient for changing students' 'exam-attitudes/behavior' with respect to 'LOCS vs. HOCS learning'. Nevertheless, whether 'HOCS-students' prefer 'HOCS examinations', whereas 'LOCS students' prefer 'LOCS examinations', remains an open question that requires further research.

As far as science/chemistry class assessment practice is concerned, take-home examinations containing both HOCS and LOCS questions (such as those used in Greek Study II and the Israeli Study) can and should be used both for assessing student progress on HOCS (reflecting the effectiveness of the teaching strategies in HOCS-oriented science courses) and identifying or distinguishing between 'HOCS' and 'LOCS' students by comparing their performance on LOCS and HOCS-type questions, respectively. The latter should be primarily directed at modifying the teaching strategies as found necessary.

Taking the three studies together, and given that LOCS-type questions predominate in most traditional exams worldwide, and are therefore familiar, and recognized by the students as straightforwardly 'solvable' and by the teachers as easily gradable, it is no wonder that they are preferred even by the best students. On the other hand, HOCS questions cause problems to the majority of students. These trends are further supported by a recent study conducted in Turkey: while 96% of the questions in three types of upper-secondary schools were of LOCS-type, more than half of the questions asked in the university entrance examination were of the HOCS type.[37] As a consequence of this, students who had high academic achievement in science lessons in schools were not able to deal successfully with many questions at the university entrance exams. It seems that non-traditional teaching and learning methodologies, such as the take-home, open-book examination, offer a good opportunity for (a) employing HOCS-type questions and problems, (b) extending the scope and depth of material taught in class, and (c) encouraging true and meaningfully collaborative learning. If the development of students' HOCS capability is indeed a major objective in current reform of science and chemistry education, then HOCS-oriented teaching, assessment methodologies, also exams and corresponding learning strategies, should become the focus of the teaching-learning process. Since the importance of enhancing the acquisition of HOCS by students is widely recognized, and was demonstrated to be feasible in chemistry/science courses, chemistry and science educators should address these and related issues, aiming at 'HOCS learning'. We believe that the LOCS to HOCS shift in chemistry and science teaching and learning not only *can* be done, but it *should* be done.

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