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HOCS-PROMOTING ASSESSMENT OF STUDENTS' PERFORMANCE ON ENVIRONMENT-RELATED UNDERGRADUATE CHEMISTRY

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ABSTRACT. The switch from traditional algorithmic lower-order cognitive skills (LOCS) teaching to higher-order cognitive skills (HOCS) learning in science, chemistry, engineering and environmental education, requires an in accord shift in students' assessment. HOCS-promoting assessment is expected to enhance students' evaluative thinking in terms of system, critical thinking – problem solving – decision making, followed by a responsible action, accordingly. The focus of this study was on the development and implementation of HOCS-promoting environmental chemistry-related exam items/questions, included in traditional exams in undergraduate chemistry, chemistry teaching methods and chemistry-related environmental education courses. These exams were administered to three groups of undergraduate, pre- and in-service science majors and science chemistry teachers at an engineering-technology and liberal arts university, respectively. The first and the third groups were not formally exposed to chemistry-related environmental issues in their courses. Our findings suggest that our undergraduate students appear to be weak on both, “making connections” and system thinking, with respect to these issues. Yet, pre-post improvement of their HOCS capability was found, particularly for the students who scored low on the pre-test. The implications for future action purposed persistent HOCS-promoting teaching and assessment, within which relevant environmental issues are integrated, have the potential of inducing ‘HOCS learning’ in science, technology, environmental, society (STES)-oriented chemistry teaching. [*Chem. Educ. Res. Pract.*: 2004, 5, 175-184]

KEY WORDS: *assessment; environmental chemistry; higher-order cognitive skills (HOCS); HOCS-promoting exam questions; undergraduate chemistry*

INTRODUCTION: THE ISSUE, RATIONALE, PURPOSE

The essence of the current reform in science education, worldwide, is the shift from the contemporary dominant traditional, algorithmic lower-order cognitive skills (LOCS) teaching to the higher-order cognitive skills (HOCS)-promoting *learning*. HOCS include question-asking, system, critical-*evaluative* thinking, decision-making, problem (not exercise) solving and... *transfer* within both, the science disciplines and real, interdisciplinary life situations in the science-technology-environment society (STES) context (Zoller, 1993, 1999; Zoller, Lubezky, Nakhleh, Tessier, & Dori, 1995). Clearly, such a paradigm shift in educational goals requires both new teaching and assessment strategies

(Zoller, 2001; Zoller, Dori & Lubezki, 2002; Dillon, 2003). This means HOCS-promoting, examinations and assessment methodology which are both consonant with the new goals, and, meaningfully, contribute to their attainment. The implementation of this LOCS-to-HOCS paradigm shift (Zoller, 1993; Zoller & Scholz, 2004) is expected to enhance students' rational and evaluative thinking, in terms of problem solving-decision making to be followed by responsible action accordingly (Zoller, 1993, 1999, 2001).

'Translation' of the above into appropriate, relevant, manageable and implementable science courses, teaching strategies and, most important, assessment methodologies, is a central issue in contemporary science/chemical education (Zoller, 1993, 1999, 2001).

The almost compulsive need in our educational systems, for extensive testing and assessment in science education at all levels, may result in stagnation, if not regression in attaining the newly emerging education instruction goals world-wide (Black, 2001). Yet, 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 (LOCS) type examinations (Tsapralis & Zoller, 2003). Moreover, despite the strong claims for need of a shift from LOCS to HOCS-promoting assessment in order to improve the quality of teaching and learning, the translation of such a shift into practice in science, science education is inhibited by conflicting pressures on teachers of external tests and in the traditional grading system in undergraduate teaching (Zoller, 1999; Black, 2001).

In view of the overly high expectations of people in a world of conflicting and competing values and finite, unevenly distributed resources, modern life has turned into a continuous process of problem solving and decision-selection from either available or as yet uncreated options. However, although science and technology may be useful in establishing what we can do, neither of them can tell us what we *should* do. The latter requires the application of value judgments by socially responsible, rational citizens as an integral part of their critical-evaluative thinking capacity (Zoller, 1993, 1999, 2001; Zoller & Scholz, 2004). We, therefore, conceptualize STES-oriented education as an educational alternative to the traditional disciplinary approach in the teaching of science (Dillon, 2002). Accordingly, a shift in science (and chemistry) education from the traditional "pure" disciplinary teaching, towards Science-Technology-Society (STS) (Solomon & Aikenhead, 1994; Dori & Hershkowitz, 1999), STES (Zoller, 1990, 1999, 2001; Keiny & Zoller, 1991) and environmental education (Dillon & Teamey, 2002) is, therefore, needed and should be translated into effective STES-oriented teaching strategies and assessment methodologies (Zoller, 2001).

Thus, meaningful environmental education is envisioned as an *interdisciplinary* system critical thinking-, problem solving- and decision making-oriented teaching leading, hopefully, to 'HOCS *learning*' in the S-T-E-S interfaces context and to the capacity of *transfer* beyond the subject(s) or discipline(s) specificity (Zoller, 1993; 1999; 2001). Accordingly, in view of the global "battle cry" for sustainable development, environment-related chemistry is increasingly being integrated in science and chemical education worldwide (Tomblonlian & Parrot, 1997; Cooper, Elzerman, & Lee, 2001; Zoller & Scholz, 2004).

The piece of research-based work here presented is complementary to related research studies purposed at cultivating students' HOCS through HOCS-promoting teaching strategies and assessment methodologies (Zoller, 1993, 1999; Zoller, Dori, & Lubezky, 2002). Its guiding rationale is, that appropriately designed HOCS - oriented examinations in science/chemistry teaching should be used in order to cultivate the students' HOCS capabilities, targeting at 'HOCS-Learning' (Tsapralis & Zoller, 2003).

Since assessment and examinations constitute an integral part of the teaching-learning process, they should not only be in consonance with the teaching and instructional goals, but also meaningfully contribute towards the attainment of these goals (Zoller, 1997, 1999). Therefore, HOCS-oriented science/chemical education requires the same orientation in assessment and examinations (Kulm, 1990; Ubrecht, 1990/1991; AAAS, 1994; Tobias & Raphael, 1997; Zoller, 1999).

The focus of this study was, therefore, the development and implementation [within traditional undergraduate general chemistry courses and courses of methods (chemistry)], of select environment-related type HOCS-promoting exam questions, and determining whether, or to what extent, the courses' participants gained in their "HOCS performance", based on the grading of these questions. Our (hidden) assumption was that the classroom evaluation practices should have been an impact on students' learning (Crooks, 1988).

Purpose and objectives

Our study was guided by our following educational objectives in science/chemistry teaching:

- to promote/foster/develop our undergraduate science majors' HOCS;
- to make chemistry learning more appealing to our students via the integration of environment-related problems and STES issues into traditional undergraduate chemistry courses;
- to enhance students' environment-related awareness, knowledge, understanding and evaluative thinking capacity.

Specifically in this study:

- to assess the extent of pre-post increase in students' HOCS *transfer* capability from "pure" (chemistry) to environmental chemistry-related domains;
- to assess students' performance and, hopefully, their pre-post gains on environment-related LOCS and HOCS questions within mid-term and term chemistry exams in traditional general undergraduate chemistry and chemistry teaching methods courses.

RESEARCH POPULATION, METHODOLOGY AND PROCEDURES

Two student populations in two universities participated in the study. One population was in an engineering- and technology-oriented university (E&T-U), and consisted of two groups: the first group were pre-service (prospective) chemistry teachers (N=19), having less than one year of teaching experience, in a traditional course of methods of chemistry teaching in their last academic year, without being formally exposed to environment-related issues during the course; and the second group were experienced teachers, having an average of 15 years of teaching experience (N=20), who took part in a specifically designed short-term chemistry-related environmental education training program. The research population in the liberal arts-oriented university (LA-U), consisted of mainly, biology, the rest being physics-mathematics majors, about half of whom were prospective science teachers, enrolling in a general and inorganic chemistry ('chem one' equivalent) course in their first academic year (N=41 pre-test; N=40, post-test). Also this population was not, formally, exposed to a specific study of environmental chemistry-related issues in the course. However, the development of their HOCS has been addressed throughout their freshman chemistry course. HOCS-type environmental chemistry/STES-oriented test items/questions (Zoller, 1993, 1999,

2001; Zoller, Dori, & Lubezky, 2002) have been developed, to be incorporated within traditional undergraduate chemistry exam questions at the two universities.

The scoring of the exam questions, by a panel of four experienced chemical educator experts, was based on both the “correctness/rightness” and, relevance/level (i.e., LOCS vs. HOCS) of the answers, with a maximum of 20 points for each question (total: 100).

The following environment-related five questions (Q₁: 1.1-1.5 and Q₂: 2.1-2.5) were interwoven in the mid-term (E₁) and term (E₂) exams and thus served as pre-test and post-test, respectively, within the research design.

Q₁: *In a battery factory workers are exposed to ZnS and CdCl₂ (in the manufacturing of electrodes), HCl (in the preparation of the electrolytic bridge); oily grease (from oily metal parts); CH₂Cl₂ (a solvent for cleaning the grease); and H₂S. A suggestion was made to replace the water by petroleum for washing the workers’ working clothes.*

- 1.1 *Do you think that the idea of replacing the water with petroleum is good from the point of view of cleaning the cloth? Explain (Question level: HOCS).*
- 1.2 *What is the possible source of the (poisonous) H₂S in the battery factory? Explain and write the relevant chemical equation (Question level: LOCS).*
- 1.3 *Based on the chemistry that you know, propose a simple practical method to overcome the H₂S problem in the factory (Question level: LOCS+).*
- 1.4 *Do you think, that the idea of replacing the water with petroleum is good from the point of view of the environment outside the factory? Explain (Question level: HOCS).*
- 1.5 *Do the terms ‘chemical bond’, ‘electronegativity’, ‘polarity’ and ‘hydrogen bond’ have any relevance to your reply to the previous question (1.4)? Explain (Question level: HOCS).*

An additional five questions (Q₂: 2.1-2.5) were incorporated in the term exam (E₂) only. The results will be discussed, qualitatively, to complement the analysis of the students’ answers. Thus, no scores of these questions are given. Rather, some of the most indicative students’ answers will be reported and analyzed.

Q₂: *Groundwater pollution by chromium, 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 CrO₄²⁻, mostly found in neutral water and HCrO₄¹⁻, mostly found in more acidic water. Both are water soluble. Usually, chromium concentrations in groundwater are less than 50 mg/liter. However, in concentrations higher than 500mg/liter the dominant ion is Cr₂O₇²⁻. In basic water Cr(OH)₃ is mainly found, which 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 CrO₄²⁻, HCrO₄¹⁻, Cr₂O₇²⁻ and Cr(OH)₃ in chromium-contaminated ground water? Explain. (Question level: HOCS).*
- 2.4 *In your opinion, what will be the effects of a particularly rainy year on the chromium toxicity risk in drinking of chromium-contaminated groundwater. Explain your answer. (Question level: LOCS+).*
- 2.5 *In your opinion, are the concepts: Oxidation-Valence, Chemical Bond, Acidity, Basicity and Electronegativity relevant, and do they have a connection, to your previous answers (2.1-2.4)? Explain. (Question level: HOCS).*

RESULTS AND DISCUSSION

The results concerning the environmental chemistry-related questions Q_1 : 1.1-1.5 are given in Table 1. Due to the poor achievements of the students on the pre-test (E_1 , Table 1), only the total weighted scores are given in the table. The students' scores on the environment-related questions in the post-test are given in Table 2.

TABLE 1. Means of students' scores (maximum possible: 100) on the environment-related Q_1 : Questions 1.1-1.5 in E_1 (pre-test).

Group	N	Mean	Total
E&T-U ¹	Preserve	19	49
	Inservice	20	32
LA-U ²	41	27	27

¹Engineering and Technology University

²Liberal Arts University

³Weighted

TABLE 2. Means of students' scores on Q_2 : Questions 2.1-2.5 in E_2 (Post-test).

	N	2.1	2.2	2.3	2.4	2.5	Total ¹
Pre-service	14	69	60	39	77	40	57
E&T-U							
In-service	16	69	62	62	52	52	59
Total/(average) E&T-U Score	30	69	61	51	70	46	50
Biology majors	32	58	77	70	58	52	63
LA-U							
Math/Physics majors	8	44	93	56	25	34	50
Total/(average) LA-U score	40	55	80	67	51	48	60

¹ weighted

In comparing the total scores (Tables 1 and 2), while taking into consideration that most of the questions (1.1, 1.4 & 1.5 of Q_1 and 2.1, 2.3 & 2.5 of Q_2 are on the HOCS level, the increase from 40 to 58 and from 27 to 60 for the E&T-U and LA-U students, respectively, suggests an improvement in the students' 'HOCS learning' with respect to environment-related issues, even significantly so. Further analysis of the students' individual, "collective" (on each question) and total scores reveals that the lower the "entry behavior" score (in the pre-test), the larger is the 'HOCS gain', as measured by the higher score on the HOCS-promoting questions in the post-test. Although this result is in agreement with that of similar studies, the results obtained in this study, as well as the data analysis, are not sufficient to point, unequivocally, to the particular reason(s) and/or specific factors that contributed to this improvement. Nevertheless, purposed application of HOCS-promoting teaching strategies, such as self-inquiry-based study, HOCS-promoting homework assignments and the inclusion of HOCS-requiring exam questions in term exams may, constitute potential contributions.

In view of the overall total improvement from the pre- to the post test, we further analyzed the results (scores) of each question in the post-test, for each of the student groups (E&T-U, LA-U). We consider questions 1.1, 1.4, and 1.5 as being at the HOCS level, whereas 1.2 and 1.3 as being "LOCS" and "LOCS+" questions.

The E&T-U students performed better on the HOCS part (Questions 1.1 & 1.4) compared with their performance on the LOCS part (1.2 & 1.3), while for the LA-U group the opposite was the case. This difference between the two groups may be due to the fact that the entry behavior, in terms of chemistry/basic knowledge, of the LA-U students was much lower (see Table 1: 27 for LA-U, compared with 49 & 32 for E&T-U, respectively) than that of the E&T-U group. Probably the LA-U students' main efforts at the beginning of the course were more focusing on the basic "knowledge domain". However, both groups scored very low on question 1.5 (HOCS). Apparently, the transfer of chemistry concepts to everyday complex situations is rather difficult to our students and should be purposely and persistently fostered and cultivated by instructors, accordingly (Zoller, 1999).

Additional environment-related HOCS-type questions (Q_2) were integrated in the post-test (only) of the undergraduate chemistry, chemistry teachings methods, and chemistry-oriented environmental education courses. The students' scores on these questions are given in Table 2. Selected most indicative students' answers are given; followed by their analysis and comparison with selected typical answers given by students to questions Q_1 in E_1 .

Both questions (1.1) and (1.2) deal with situations unfamiliar to the student. On the one hand, both problems require basic knowledge that students are usually exposed to during their general chemistry courses (the LOCS part). On the other hand, however, the most meaningful part of the students' answers is expected to include their capability for making connections, analysis and decisions, based on their understanding and conceptualization *beyond* knowledge *per se* (the HOCS part).

Similar criteria were applied in the grading of students' answers to these questions which required, in some parts (e.g., in question 1.3), mainly relevant knowledge; i.e., LOCS on the students' part. The HOCS parts of the problems include, in e.g., 1.1, the students' explanation of the environmental effects in using petroleum instead of water. Most students stated that water is much "friendlier" to the environment than petroleum, and, therefore, it should be preferred. Others, however, disregarded the fact that the water used in the battery plant is polluted and should, therefore, be handled accordingly. In the Q_2 questions on E_2 , it was important to assess the way the student connects the toxicity of a substance with its oxidation number (in 2.1) and, in what way (if at all), the student would reach the conclusion, that acid rain is expected to increase the concentration of the more toxic Cr(VI)-containing ions (in 2.3).

In Q_2 , question 2.4 deals with the difference between concentration and total amount, considered by us to be on the LOCS+ level. However, the most important part of the answer is to interrelate these two different scientific concepts with respect to their short- and long-term impact on the environment. This requires HOCS.

Questions 1.5 and 2.5 checked the students' capability to connect between theoretical scientific concepts; e.g., electronegativity and polarity (to both of which the students were previously exposed during the lectures) with everyday-practical environmental problems. Clearly, making this connection requires HOCS.

The following are a few selected examples of "typical" representative students' answers which relate to some basic chemical concepts.

Student A – In response to 1.1:

“... In order to get rid of the different undesirable substances they should be dissolved or dissociated (!).”

“... ZnS, HCl and H₂S are polar molecules. Therefore, they will dissolve in water. CH₂Cl₂, CdCl₂ [(!)] and grease will *dissociate* [(!)] much better in petroleum since they have a non-polar structure. One should also consider the possible damage of petroleum to the clothing...”

In response to 1.3:

“... Water is “friendlier” than petroleum to the environment and it won’t be too difficult to clean it from the pollutants. To clean the petroleum will be much harder [(!)]. Also, traces of petroleum on the clothing may be harmful to people’s skin.”

In response to 1.5:

“... Chemistry is the most relevant science in dealing with environmental problems. Usually people who are not chemists do not use the proper scientific concepts.”

Student B – In response to 1.1:

“... It seems to me to be a good idea to use petroleum instead of water, since not all the given substances dissolve in water.... For example, CH₂Cl₂ is non-polar too [(!)] and, therefore, dissolves in petroleum. ZnS and HCl are polar molecules and will dissolve in water, i.e., H₂S is a gas, so we should not worry about it [(!)]. Substances will bond to a solvent that has a similar bond structure.”

In response to 1.3:

“To use petroleum is a good idea only with regard to substances that we want to get rid of, not with respect to environmental problems. It will be difficult to dispose of the polluting petroleum.”

“Polluted water can be cleaned by distillation or filtration [(!)]. There is a world shortage of fossil fuel or oil, and we should use it carefully. I think it will be better to use water.”[(!)]

In response to 1.5:

“The concept of chemical bond is associated with the bond between the petroleum molecules (the solvent!) and the different solutes.”

“... Hydrogen bond exists between hydrogen and an electronegative element. Such a bond exists between petroleum molecules and solute molecules...”[(!)]

Few comments on the authors’ part, concerning the above pertain, mainly, to the LOCS-type questions, follow.

In general, students had some conceptual difficulties in differentiating polar from non-polar substances, as it is evident in the two answers of students A and B (LOCS level). They did *know*, however, the solvent/solute “rule”. Thus, it seems that there exists a confusion regarding what the dissolution process means; that is, are new chemical bonds being formed between solute and solvent? Do substances of the solute dissociate in that process? Is the latter connected to the “nature” of the solvent and solute? If a solution is formed, can it be separated by filtration? The relation of all of the above to the

misconceptions issue is clear. It also pertains to the students' responses to Q2.

In their response to 1.5, most of the students responded quite vaguely and only in a very general way (see e.g., student A). Student B (and a few others) tried to respond more specifically. However, even though he/she recalled the *definition* of hydrogen bonds he/she was unable to apply it properly. Student B also had difficulty in making a *decision* concerning the substitution of water by petroleum in the cleaning process. In fact, he changed his mind in the course of his answer (see his responses to questions 1.1 and 1.3).

The following are typical (representative) students' responses to Q₂:

- 2.1 "Cr(OH)₃ is hardly soluble in water. Therefore it is the least poisonous substance."
- 2.3 "Acid rain will cause some difference in the amount of the various substances. For example: acid rain will neutralize Cr(OH)₃ and will cause an increase in the HCrO₄¹⁻ concentration, since it dissolves better in acidic solutions."
- 2.4 "A very heavy rain season will be beneficiary, since the large amount of water will dilute the poisonous chromium substances."
- 2.5 "... In my view, there is a connection between scientific concepts and the questions raised in that problem. One should understand the difference between ionic (for example Cr-O) and covalent (O-H) bonds and what is meant by acid rain..."

As shown in typical answers cited above, the majority of the students disregarded the fact that in the different substances containing Cr, the oxidation number of the Cr atom varies and that the toxicity of the substance may, somehow, be connected to this fact.

The low solubility was taken by the students as the *only* factor which determines the low toxicity of Cr(OH)₃. This is quite amazing, since in question 2.5 the concept of oxidation was mentioned and, needless to say, this topic was previously "covered" in the course class. Such a "common" response should turn on a 'red light' whenever we assume that students will make the right "connections" in complex systems just by algorithmics/LOCS teaching/covering of a specific item such as an oxidation number.

Students' general approach in responding to question 2.4 (based on 51 responses) was analyzed with the following results:

- 2.1 High concentrations are harmful to living systems ("Yes" answer)
- 2.2 The total amount is the major factor ("No" answer).
- 2.3. "Yes" in the short run, but it is not a good idea in the long run ("Yes"/"No" answer).

In general, most students showed awareness and knowledge (LOCS) concerning the difference between the concentration and the total amount (81%). The majority of the students just responded by "Yes" or "No". They either claimed that the total amount is the important factor, and dilution will not solve *any* problem (35% gave a "No" answer), or claimed, that dilution will solve the problem *completely*, since low concentrations of poisonous substances are less harmful (24% gave a "Yes" answer). However, only 8% of the students explained the difference between the short- and long-term effects of the poisonous substances on the environment ("Yes/No" answer). This suggests that students tend to prefer absolute ultimate "correct" answers, as they are used of doing when they solve algorithmic problems, even when they are faced with more complex situations.

With respect to question 2.4: Some students suggested that other "methods", instead of dilution, should be used in order to decrease the chromium-ion concentration and amounts in groundwater (14%). The remaining group of students (19%) did not answer this question at all. Probably these students lacked the basic knowledge concerning the difference between concentration and total amount of the solute. Interestingly, in responding to this question (2.4), most of the students dealt with the issue by reasoning that due to dilution of the

polluting substances caused by the heavy rain, the overall toxicity will decrease. Only very few students expressed the idea that dilution will help only in the short run (in that specific rainy year), but in the long run, the toxic substances, which persist in the environment, will pollute the relevant water resources.

With respect to question 2.5: Here, again, as in the case of Q1 in the pre-test, most of the answers were on a general level. Some students tried to answer more specifically but their responses were only partly correct. For example: "... Oxidation number and valence number show how chemically active is a substance in a specific reaction." However, this (same) student disregarded the particular oxidation number of chromium as a possible factor for its activity-toxicity. As stated before, distinction between HOCS- and LOCS-levels of student responses served as the basis for the assessment/grading of the entire pre- and post (mid-term and term) exams in this study. Also, significantly, the students' overall general chemistry exam scores were, almost with no exception, higher than those on the environment-related Q₁ and Q₂ questions in the pre- and post-tests, respectively. This fact points at the difficulties of students to apply and transfer theoretically learned topics to environment-related problems.

SUMMARY/CONCLUSIONS AND IMPLICATIONS

Our undergraduate science major students appear to be weak on both, "making connections" and inclusive (system) thinking, with respect to chemistry-related environmental STES issues and concerns. Whether the above is due to the students' lack of either basic chemistry knowledge, or chemistry-related "environmental knowledge", or ... low "HOCS capability" (or all of the above), cannot be deduced from the data/results of this study. The students appear, nonetheless, to improve on 'HOCS learning' during the pre-post-test period, those of the lower entry 'HOCS behavior' are benefited most. Whether this suggests that chemistry knowledge per se, is an important contributor in this respect remains an open question. Nevertheless, the implication for future action as far as STES-oriented, HOCS-promoting chemistry teaching and assessment are concerned, is two-fold: Well-designed HOCS-promoting teaching strategies should be implemented and relevant chemistry-related environmental issues should be integrated within chemistry teaching, in order to increase students' capability to meaningfully deal with them. In STES-oriented chemistry courses, the implementation of an appropriate HOCS-promoting assessment for grading students' performance on HOCS-type exam questions is self-evident.

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