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Research-Based Transformative Science/STEM/STES/STESEP Education for "Sustainability Thinking": From Teaching to "Know" to Learning to "Think"

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Abstract: Sustainability is conceptualized, approached and acted upon differently by people, sectors, societies, nations and educational systems. Consequently, the "sustainability thinking"-related scientific, technological, environmental, societal, economic and policy/political components are expected to transform differently. The related necessary transformative paradigm shifts in science, technology, environment, society, economy and policy (STESEP)—*education* from the contemporary disciplinary science, technology and environmental teaching to "know"—to transdisciplinary learning to "think" are to be expected. The overriding purpose: ensuring "sustainability thinking" by responsible, capable "STESEP literate" citizens. Consequently, "sustainability thinking" in the STESEP interfaces contexts, requires (1) the development of students' higher-order cognitive skills (HOCS) via a transformative/transdisciplinary "STESEP Education"; (2) a research-based shift from the conventional algorithmic lower-order cognitive skills (LOCS)-based teaching to "know", to "HOCS learning" to "think"; and (3) a special focus on HOCS-promoting teaching, assessment and learning strategies in science, technology, engineering, mathematics, environment, society and education. A pre-post research design of system thinking, evaluative thinking, and decision making capabilities of 10 grade high school, undergraduate and graduate students, in Israel, are presented and discussed in the learning for "sustainability thinking" context. In conclusion: contemporary science education in secondary and tertiary levels is mainly, disciplinary (biology, chemistry, mathematics, physics) in science, technology and engineering courses. The LOCS-to-HOCS paradigm shift still constitutes a major issue of concern, with respect to ensuring a transformative science/STESEP education, targeting "sustainability thinking" in secondary and tertiary education.

1. Introduction

"Sustainability" has been considered traditionally to be a guiding framework for economics, research and development (R&D), mainly technologically, socially and politically, all to be pursued while maintaining an equilibrium with environmental conditions. Pretty fast, "sustainability" has become the buzzword of our 21st century modern society; just about everything must be sustainable [1,2]. Thus, the assessment of "sustainability" via integrated sets of sustainability indicators of global development points to the fact that life expectancy, living standards, gross domestic products and food production per capita, accessibility to safe water, public health, and human freedom increased steadily [3]; in contrast, other sustainability indicators point out that other components have significantly decreased [4]. Yet, since sustainability is conceptualized differently in different countries, societies, cultures, sectors and systems, it will be acted on *differently* locally and globally.

Although science and technology may be useful in establishing what can be done, as well as opening up new options, neither can tell us what should be done; the later requires not just information-based "knowing" but rather, more so, "sustainability thinking"-based action for ensuring "sustainability". Yet, contemporary science, technology and environmental education and the related assessment of students' learning are, mainly disciplinary "knowing", and not inter/cross/trans-disciplinary "thinking" focused.

Given the current strive for sustainability and the corresponding paradigms' shift in science, technology, environment perception, economy and policies—e.g., from unlimited growth to sustainable development—the corresponding paradigms shift at all levels of science, technology, environment, society (STES), science, technology, engineering, mathematics (STEM), and environmental education are unavoidable. A sound, meaningful and coherent science and education for ensuring global sustainability requires a revolutionized change in the guiding philosophy, rationale, and models of our contemporary thinking, behavior, and action [5–11]. The related development of students' "sustainability thinking" in the science, technology, environment, society, economy and policy (STESEP) education, requires the development of higher-order cognitive skills (HOCS) such as question asking, system-, critical- evaluative thinking, problem solving, decision making as well as moral thinking, creative thinking and transfer (Figure 1) in these contexts [5,9–11].

Science, technology and environmental education at all levels worldwide, have been and still are based on teaching to know, followed by assessment of the students' knowledge gain. The bottom line: the teaching for subject matter "knowing" *per-se*, requires just the "traditional" algorithmic lower-order cognitive skills (LOCS) teaching to be applied and exercised. However, "sustainability thinking" literacy requires a purposed development of students' HOCS since knowledge *per-se* is not sufficient for meaningfully dealing with "sustainability" in the STESEP interfaces context. Furthermore, research based coherent science/STEM/STES/environmental education (SSSEE)

constitute the pillars of education for 'sustainability thinking' and sustainability. Their research-based development is here presented [5,8–14].
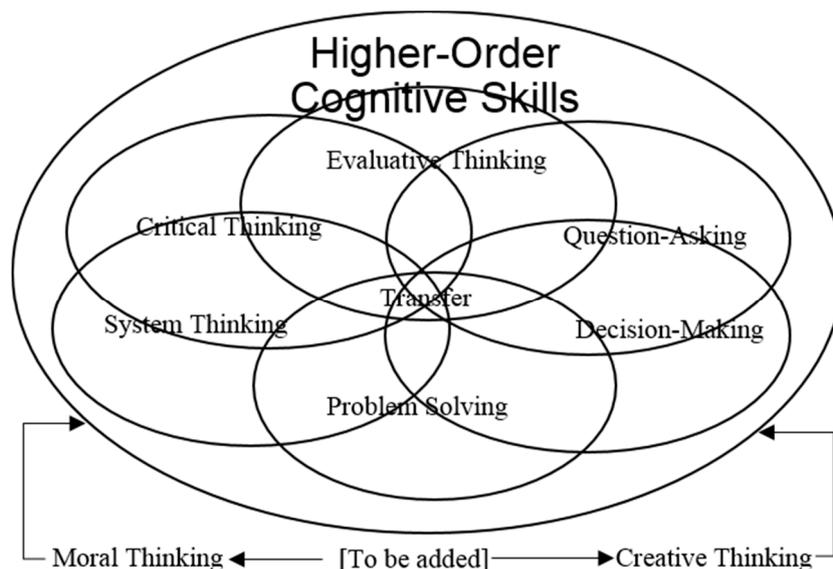

Figure 1. The guiding conceptual model of HOCS in the context of science education and SSSEE [5,8,15,16].

The challenge of 'STESEP literacy' will require the restructuring of science, SSSEE and education at large via research-based implementation of HOCS-promoting teaching, assessment and learning strategies, which are necessary in dealing with complex systems in the context of the case study methodology. Such transdisciplinary case-based learning is expected to facilitate both students' and communities' of societies' stakeholders at large to become "sustainability thinking" literates and active participants in their sustainability STESEP realities.

The core issue of this manuscript is STES Education for "Sustainability Thinking" (SEfST). Its structure reflects what SEfET is all about and how to through research transform from the conventional dominating teaching to "know" to learning to "think". In accord, SEfET is to be based on a purposed shift from the conventional science teaching to the HOCS model-based learning.

Sections 2 and 3 expands on the problems, rationale and conceptualization in relation to SEfET and what is needed in order to achieve the goal of "Sustainability Thinking" in the STESEP context. Sections 4 and 5 focus on the objectives, goals, related assessment, research design, procedures and methodology applied in the context of SEfET.

Section 6 presents selected research results related to the HOCS of system thinking (ST) and evaluative thinking (ET) capabilities science students in secondary education, followed by those of decision making (DM) in tertiary education in Section 7. The conclusions and implications (Section 8) are discussed regarding the DM-related research. They refer, however, to the entire research results presented in this paper.

2. Education for Sustainability Thinking: What Is Necessary?

Sound STESEP education for "sustainability thinking" is envisioned as an inter-transdisciplinary HOCS-promoting teaching and assessment of critical/evaluative and system thinking, decision-making, problem solving, moral and creative thinking. The ultimate goal is the advancement of students' "HOCS learning", which is essential for transfer in the "sustainability thinking" context, in which moral and creative thinking constitute integral components [5,8,15–17]. All of the related HOCS are expected to be applied by students beyond the science/STEM/STES/STESEP environmental education (SSSEE) disciplines to the complex problems needed to be addressed and, in accord, decisions to be made in the context of sustainability and "sustainability thinking" locally, regionally and/or globally. Thus, a purposed effort in the context of "sustainability thinking" is needed for ensuring the shift from LOCS teaching to HOCS learning in both secondary and tertiary levels. Such a fundamental transformative shift from the traditional science education to KNOW to "sustainability thinking" needs to be research-based in order to ensure the sustainability component in STESEP education for "sustainability thinking". Such a process is expected to facilitate the preparation of students to become sustainability- and socially-responsible citizens [14–17]. In contrast, traditional algorithmic LOCS-based science teaching, which focuses mainly on the knowledge paradigm, appears to lack in its capability of developing decision makers and/or problem solvers to be active in the sustainability contexts. In order to achieve the goal of sustainability thinking for action, the focus of "sustainability education" needs to be redirected from the learning of facts to the development of students' HOCS and the latter's to be translated into action within the transformative "sustainability thinking" teaching, assessment and *learning* processes.

"Sustainability thinking" in SSSEE is embedded in the HOCS conceptual model (Figure 1). It requires research-based development of students' HOCS via coherent inter-transdisciplinary *generic*, contextually-bound teaching, to be followed by research-based HOCS-promoting assessment methodologies of "sustainability thinking". In accord, meaningful science education for "sustainability thinking" requires an inter-trans-disciplinary *teaching* approach which promotes question asking, critical/evaluative system thinking, problem solving and decision-making as well as further development of HOCS, all targeted at the enhancement of students' "HOCS learning" for application in non-algorithmic situations and realities. Indeed, the development of students' HOCS capabilities have shown to be attainable [5,15,17]. Given the sustainability-related paradigm shift already underway—e.g., from unlimited growth to sustainable development; correction-to-prevention; wants-to-needs; gaps increase to gaps decrease; passive consumption-to-active participation; and options selection-to-options generation [5,8,9]—the corresponding paradigms shift, particularly as far as development, growth, rational consumption, management of resources, economics and policies in the STESEP contexts are getting momentum [1,3,6,7,13]. The related research-based recommended paradigm shifts are presented in Table 1 [5,8,13,17].

Table 1. Selected paradigms shifts in science, technology, environmental, and STES/STEM/STESEP-oriented science education and the related research [5–17].

From:	To:
• Technological, economical, and social growth at any cost	Sustainable development
• Corrective responses	Preventive actions
• Reductionism: dealing with *in vitro*, isolated, highly controlled, decontextualized components	Uncontrolled, *in vivo* complex systems
• Disciplinarity algorithmic exercise solving	Problem-solving orientation with decision making- based on systemic, Inter-, cross-, transdisciplinary approaches
• Technological feasibility	Economic and social feasibility, socially accountable, responsible
• Algorithmic lower-order cognitive skills (LOCS) oriented teaching	"HOCS Learning" in the STESEP interfaces context
• "Reductionist" thinking	Systems/lateral thinking
• Dealing with topics in isolation or closed systems	Dealing with complex, open systems
• Disciplinary teaching (physics, chemistry, biology, *etc.*)	Interdisciplinary teaching
• Teaching to 'know' and assessment of 'knowing'; e.g., applying algorithms for solving exercises	Conceptual learning for problem solving and transfer—for 'thinking' in the STESEP contexts
• Teacher-centered, authoritative, frontal instruction	Student-centered, real world, HOCS-oriented (team) learning

3. Subject/Problem; Rationale, Conceptualization, Purpose and Objectives

There is an ever-increasing mismatch between the reality of the 21st society, which is based on science, technology, globally interacting economies and advanced sophisticated, deep penetrating network systems which enhance the information and *knowledge*-based capabilities of people and the educational systems that respond quite *similarly* to this reality. Thus, educational systems are perceived as an instructional framework, the objective of which is to advance pupils/students up the classes' ladder, based on their highest scored passing of *disciplinary*, mainly *algorithmic*, *knowledge-centered exams* and/or "*standardized*" *tests* [18]. Pupils/students' *learning* is assessed and being valued according to their "grade achievement" being the exclusive criteria in these algorithmic-based tests/examinations. This conventional/traditional SSSEE does not resonate with the "STESEP literacy" conceptualization. The latter requires the development of students' thinking transfer capabilities in the STESEP contexts via the corresponding HOCS-promoting teaching, assessment and *learning* strategies [12,16,17,19,20]. In turns, this means a shift, within different educational systems, from the currently dominating LOCS algorithmic teaching-to-know, to HOCS-promoting learning-to-think, particularly with respect to question asking, critical, system and evaluative thinking, decision-making, as well as moral and creative thinking, all of which are required for problem not exercise solving [5,16–20], transfer and "sustainability thinking". Such teaching and

learning for *thinking* are emerging followed by research-based implementation in different settings and modifications at all levels of SSSEE education, worldwide. Selected research-based methodologies to implement: open books examination where the students ask the questions [21], mini-projects, group work, *problems*-based learning and take home examinations.

Clearly, such a "LOCS-to-HOCS" paradigms shift in conceptualization, thinking and education, needs to be consonant with, and enhanced by, *generic* trans-intra- interdisciplinary and contextually-bound research-based "sustainability thinking" teaching strategies and assessment methodologies targeted at their integration into SSSEE [5,14–17,19–25]. They have been shown by research to be interrelated to one another in STESEP contexts and to empower the students'/learners' capability of "sustainability thinking" and conceptualization [5,14–17,20–25]. Consequently, SSSEE teachers, educators, researchers, economists, politicians, cognitive psychologists and sociologists consider the development and assessment of students' HOCS capabilities to be important in the assessment of students' (our future citizens)—*learning* within the STESEP 'sustainability thinking' paradigm. This "sustainability learning" reflects the continually increasing social pressure worldwide, towards more accountability—socially, environmentally, economically and politically, in relation to the sustainability context [5,6–9,14,24,25]. In short: thus, "sustainability thinking" requires a corresponding research-based transformative paradigm shift, from the traditional algorithmic knowledge-based teaching to 'know' to learning to think; that is: from algorithmic-based teaching to HOCS-promoting *learning* to think [5], and SSSEE teaching to "know" to *learning* to "*think*" in the STESEP interfaces contexts.

The "Sustainability Thinking" goal via the "STESEP Problems Solving Decision Making Act" means [5,16,17,25,26]:

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

The activities 10–13 are not proposed to be necessarily applied in the given order. Hence, the development of students' 'sustainability thinking' constitute an alternative to the existing "traditional" linear SSSEE in class practice of teaching disciplinary knowledge and students' "test wiseness"-oriented LOCS level algorithmic instruction. Alternatively, a research-based transferable "HOCS learning" has been and is here reproposed to become the "king's road" for empowering students toward rational, effective and responsible active participation in whatever role they might play in society. In short: the development of the students' capability of rational-reflective evaluative thinking, pre-decision making or

problem solving, concerning what to accept or reject, do or not to do in what way, followed by taking a responsible action accordingly [5,9]. This has the potential of paving the way to (a) socially *creative* and scientifically literate person, having the appetite, readiness and motivation to enquire, think, learn, grow and (b) concomitantly maintaining the capability to collaborate with her/his peers. Therefore, the nurturing of *excellence for all* in a broad spectrum of fields and contexts, social sciences included, is envisioned as a vital overriding goal in SSSEE teaching and learning for "sustainability thinking" and sustainability.

4. Objective, Goals and Related Assessment Tools

Guided by the HOCS conceptual model (Figure 1), the objectives of SSSEE for the development of students' "sustainability thinking" are:

(1) The development of students' HOCS, particularly questions asking, critical evaluative system thinking, decision making, problem solving and transfer [21–28].
(2) The teaching of SSSEE for acquiring learners with new types of sustainability relevant competencies.
(3) The development of students' awareness and appreciation of STESEP-related concepts.
(4) The development of students' awareness and appreciation of the significance and meaning of *various* possible alternative solutions and/or resolutions to a problem at point.
(5) The development of students' awareness of short- *versus* long-term consequences in the STESEP interrelated contexts.

In our STESEP education-related longitudinal research, we have targeted fostering the shift from algorithmic teaching and assessment to a HOCS level sustainability-related *learning*, followed by obtaining research-based answers to the following selected core questions:

(1) Does *traditional* science instruction leads to gains in, and development of students' capabilities of *system thinking* (ST), *evaluative thinking* (ET) and *decision making* (DM)?
(2) What are the science students' views concerning their capability of resolving HOCS- requiring problems in SSSEE and sustainability related contexts?
(3) What can be learned from students' responses to HOCS-requiring problems, to be used for promoting their generic, inter-transdisciplinary HOCS capability in the sustainability STESEP education for sustainability contexts?

5. Research Design, Procedure, Methodology and Assessment Tools

A pre-post designed quantitative and qualitative 2–3 years duration of research projects has been conducted in available "representative" science classes (~20–30 students in each), focusing on system thinking (ST), evaluative thinking (ET) and decision making (DM) capabilities in high schools and colleges/universities in Israel. In the control classes, the "traditional" LOCS-"algorithmic" science teaching and assessment have been continued whereas HOCS-promoting methodologies; e.g., the students, not the teachers ask the questions, solves problems (having more than one *correct* answer) which require their capability of system/critical thinking as well as decision making (DM) capabilities. Thus, teaching and assessment strategies which previously demonstrated to promote the HOCS

capabilities—questions asking, open books, and take home examinations as well as group work were applied. Specially developed, validated by experts and "interrated" questionnaires (two, almost identical, pre-post versions) were pre-post administered and the students (in both experimental and control classes) were requested to respond to these actually opinionaires/"response-nairs"/HOCS-promoting questionnaires [5,15,20,27]. All of the above is based on previous HOCS-related research studies and the "responsenaires" pre-post administered to the students' research populations [5,17,26] during the study period in the treatment/experimental classes (10th–12th grades in secondary schools) and during one semester in college/university science courses. The above was accompanied by class observations and semi structured interviews of both teachers and students. The results/findings have been analyzed, first qualitatively; *i.e.*, the LOCS-to-HOCS ordinal categorization of the students' responses, followed by numerical scoring: 0, 1, 2 for no response, superficial, not relevant LOCS and HOCS levels responses, respectively. This was followed by quantitative statistics of the students' scores which, in turn, were used for determining the distribution of the students' responses' scoress/scoring on the 0, 1, 2 LOCS-HOCS scale (see, for example, Table 3). The conclusions and implications derived from the findings were based on the analysis and grading the level of students' responses and their scouring in both the statistical and the qualitative parts of the research studies.

6. Selected Research Results

System Thinking (ST): The pre-post (two school years) ST capabilities of 10 grade science and environmental studies students in two schools, private and public, in the multi-sectorial educational system in Israel, have been assessed via the administration of a specially developed (and pre-validated) ST questionnaire and its administration in the research classes (Table 2).

Table 2. Average scores of science and environmental studies students on their system thinking (ST) capability (on a LOCS-HOCS scale).

Strand	N	Score		SD	Δ Score	*t* Value	*p*
		Pre	Post	p/p			
Science	49	14.92	17.35	3.58/3.19	−2.43	−5.33	0.001
Environ. Studies	43	12.35	16.72	2.77/3.20	−4.37	−7.55	0.001

The results point to a statistically significant post-pre difference improvement in the ST capabilities of both groups, more so in those of the science environmental studies. However, the average ST "capability score" of both groups was low, most probably due to the limited contribution of traditional (frontal) mode of SSSEE teaching to the development of this ST-HOCS capability.

Evaluative Thinking (ET): The statistics results of a pre-post designed research (in Israel) concerning high school science students' ET capability on the LOCS/HOCS levels, based on their responses to the pre-post administered questionnaires (the post questionnaire is given in Appendix), are shown in Table 3.

Significantly, the fact that about one third of the students' responses were on the HOCS level (Table 3), may suggest that 10th-graders who have been taught science in the traditional manner do have the *potential* of coping with learning tasks on the HOCS level. Therefore, this result reflects an acquired ET capability in this case study. However, the result showing that about 70% of students

achieved just the LOCS-level constitutes an area of concern (Table 4). This suggests that a deliberate development and promotion of the ET/HOCS in secondary education is needed, in order to support the paradigm shift from teaching to "know" to learning to "think", particularly in SSSEE in the sustainability STESEP contexts.

Table 3. Overall pre-post frequencies (%) by no response, LOCS and HOCS (0, 1, 2) levels of the research population's responses to the questionnaire ($n_{total} = n_c + n_t = 219$) *.

	Cognitive Level Responses Pre Post					
	0	**1**	**2**	**0**	**1**	**2**
Control classes ($n_c = 178$)	13.0	75.3	11.7	1.9	65.9	32.1
Treatment classes ($n_t = 41$)	8.9	64.6	26.5	2.9	48.1	49.0
Total	12.5	73.3	14.2	2.1	63.1	34.8

Note: $p < 0.001$; * n_c, n_t—number of students in the control and treatment classes.

Table 4. Overall frequencies (%) by LOCS/HOCS levels of high school students' responses (total 5910).

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

The results of the students' "LOCS/LOCS-HOCS/HOCS" distribution (Table 5) show that there are gaps between the proportion of "LOCS" and "HOCS" students in both Arab and Jewish sectors. The findings are in accord with those presented in Table 5, which suggest that perhaps culture and availability of resources in different sectors have an impact on the development of students' HOCS in multi-sectorial education systems. Our finding that ~54% of the research population were on the "LOCS" level, while only ~31% on the "HOCS" level (Table 6), points at the need and importance of fostering and developing the students' "HOCS learning" capabilities. This would require a profound change in educational systems that target HOCS-promoting teaching and assessment strategies in secondary school systems.

Significantly, very minor gender differences were found in both sectors on the categorization of the students via LOCS, LOCS/HOCS and HOCS levels (Table 6). A plausible (possible) interpretation: the major gender-related issues in SSSEE are similar in multi-sectorial educational systems.

Table 5. Categorization of students (%) along the LOCS- HOCS scale by sector and total.

Population	LOCS Students (%) 0–4 HOCS responses		LOCS/HOCS Students (%) 5–7 HOCS Responses		HOCS Students (%) 8–15 HOCS Responses	
Sector	Arab	Jewish	Arab	Jewish	Arab	Jewish
	82.8	28	13.11	20	4.07	52
Total (J&A)	58.59		16.16		25.26	

Table 6. Categorization of students by male/female and by sector, along the LOCS-HOCS scale. In the Arab sector # of F = 120, # of M = 99; In the Jewish sector # of F = 101; # of M = 74.

Population	LOCS Students (%) 0–4 HOCS Responses		LOCS/HOCS Students (%) 5–7 HOCS Responses		HOCS Students (%) 8–15 HOCS Responses	
	Arab	**Jewish**	**Arab**	**Jewish**	**Arab**	**Jewish**
Females in each sector	82.6	30.69	14.06	18.8	3.31	50.42
Males in each sector	82.84	24.32	12.12	21.63	5.05	54.07

7. Decision Making (DM)

As was mentioned in the outset of this paper, 'sustainability thinking' in the STESEP interfaces contexts requires the development of HOCS (Figure 1) in the SSSEE contexts. The HOCS capability of decision making is a key component in education for sustainability thinking (EfST).

The development of students' DM capability, as well as other HOCS capabilities in the inter-disciplinary STES and STEM context, is one of the overriding goals of contemporary science education reform, at all levels [9,14,25–29]. In STESEP-oriented science education, the DM process is conceptualized as the application of a choice among existing possible options, or newly generated ones.

Thus, the development, of competent "decision-makers" in science education is significant in terms of: (a) facilitating sensible and reasonable decisions in complex reality; (b) making society function productively at all levels, with minimal social friction; (c) enhancing the prospects of the survival of individuals and communities; and (d) educating students to understand and appreciate decisions of others. These would enable our future citizens to become actively involved in the democratic economical-political process in the STESEP context. Hopefully, these four objectives present an appropriate response to the challenge posed by society to modern SSSEE with respect to "sustainability thinking".

7.1. Decision Making in Tertiary Education

The following research probed the DM capability of undergraduate science students in Israel's higher education, compared with that of graduate (MA) students who were exposed to a DM/HOCS-promoting teaching. The guiding research questions were: (1) What is the contemporary DM capability of science students in Israeli higher education? (2) What is the complexity level of the questions they ask within the teaching-learning processes? (3) To what extent are the treated students capable of providing relevant rationalization for their decisions? and (4) Are they capable of estimating whether social values and political considerations are involved in their decisions?

7.2. Methodology

Research population: The sample comprised of 131 university and college students in four representative (approachable) classes in tertiary education universities and colleges in Israel: (1) B.Ed. pre-service prospective science teachers in a teaching college (Group-1; $N_1 = 30$); (2) B.Sc. university freshman science students (Group-2; $N_2 = 45$); (3) B.Sc. science students in a technological university

(Group-3; $N_3 = 30$); (4) MA students, in a first year course within the department of Management of Natural and Environmental Resources(Group-4; $N_4 = 26$).

Based on the quite similar scoring results of the undergraduate students in Groups 1, 2 and 3, compared to that of the graduate MA students in Group 4 ($N_4 = 26$) [Tables 7 and 8], the first three were 'combined' into Group T ($N_T = 105$) and the results of both groups were interpreted accordingly.

Instrument and Procedure: The specially developed *Evaluation DM Questionnaire* (*EDQ*) [5,9,12,26] was used for evaluating the students' DM capability. It was validated by three science educators, experts in HOCS/LOCS-related research, whose scoring of students' responses provided an inter-rating level of 0.85.

The EDQ was administered to the research students' population who were requested to read the following 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 are 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.

The students were then requested to briefly respond to the questionnaire items.

Data Analysis: Students' responses were analyzed, first qualitatively, and then quantitatively-statistically. Similar to the methodology used in the ST and ET research studies, an ordinal scale-based categorization of the responses was followed by their scoring: 0, 1 or 2 for: no response, superficial, or non-relevant, LOCS and HOCS levels, respectively. LOCS-level responses that scored 1 were those that demonstrated a simple recall of information, application of known knowledge and/or known (to the students) algorithm(s) to familiar situations and contexts. HOCS-level responses that scored 2 were those that demonstrated application of one or more HOCS capabilities such as: critical thinking, system thinking, decision-making, problem-solving, evaluative thinking, a mixture of these and transfer [15].

Referring to the questionnaire:

Item 1: "Formulate three questions that you would like to, or think, are important to ask concerning the subject(s) dealt with in the paragraph". The criteria for scoring the students' responses were (as previously explained) the level—LOCS or HOCS—of the questions asked, operationally defined in our previous studies [30]: No, or trivial response, LOCS-level and HOCS-level responses were scored: 0, 1 and 2 points, respectively, for each question asked. The results were statistically summarized in terms of the number and percentage of participants in each group level: -0, LOCS-1 and HOCS-2.

Item 2: "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". Participants' responses to this item were analyzed in terms of (1) the respondent's willingness and capability to choose, or not

to, among the provided alternatives; and (2) the quality of respondent's rationalization, explanation(s) and justification(s) of the decisions made. The related scoring was (as before): 0, 1 and 2 points for no response, or trivial/shallow argument, not-explained, or not-rationalized DM and for applying relevant conceptual knowledge, respectively, followed by related justification for choosing a particular alternative. Further statistics of the scoring results provided the percentage of participants' responses in each of the three categories.

Item 3: "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". The participants' capability to rationalize the advantages and/or disadvantages of their selected energy resource(s) was evaluated in terms of the relevance and complexity levels of the responses: 0—no response; level 1—irrelevant explanation(s) and/or one's incapability of making or rationalize a decision (LOCS); level 2—criterion-based explanation(s) (HOCS or LOCS); and level 3—criterion-based explanations and rationalization, advantages and disadvantages of the chosen (or not chosen) alternatives (HOCS). The qualitative results were summarized, followed by scoring (0, 1, 2) and chi-square statistics of the students' responses.

7.3. Selected Results and Discussion

The initial qualitative, followed by a quantitative analyses of the results revealed that Group 4 of the MA students (N_4 = 26) differed, statistically, from the other research groups. A further chi-square statistics revealed a significant difference between the MA Group 4 students and the other students in the sample with respect to the level of questions asked (Table 7). The distribution of HOCS level of questions asked was 72.9% in Group 4 *vs.* 48.6% in Group T (Table 7), which is in full accord with the significant difference between the two groups in their related level of question asking. This may be rationalized by the purposely applied HOCS-orientation, both didactically and contextually, in the MA class, compared to the traditional LOCS-orientation in the science courses in both undergraduate tertiary and secondary education.

Table 7. 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	$p < 0.0004$

The following quotes illustrate participants' "typical" LOCS and HOCS level questions:

LOCS level: (1) "What are available and non-available resources and what is the difference between them?" (2) "How can one produce liquid fuel from coal?"

HOCS level: "What are the future impacts of each alternative? Can disastrous results be avoided?" "What are/should be the guiding and determining considerations of the decision concerning which resource to use?"

Item 3 in Table 8 refers to students' capabilities to explain and justify their decisions in terms of *'the complexity level'* of the decisions made. The results indicated that about 22% of Group T students justified their decisions on the LOCS/HOCS (level 3) of complexity, compared to 17% on the HOCS (level 3). The corresponding levels of the MA students (Group 4) were 39% and 27%, respectively [Table 8]. These results are compatible with the results of the question asking/DM capabilities (*Items 1 and 2* in the EDQ. Thus, the *complexity level* of the DM process is a useful parameter according to which DM capability is effectively assessed.

Table 8. Part III only: Group T (N_T = 105) and Group 4 N_4 = 26 distributions (%) by the decision making rationalization complexity level (Items 1, 2, and 3).

(III) Rationalizations' complexity	Group-T (N = 105)	Group-4 (N = 26)	Chi^2 Test
No explanation	46.47	11.50	
Irrelevant explanation—incapable of making a decision	14.27	23.10	DF = 3
Using defined criteria for positive or negative answer	21.90	38.50	x^2 value = 10.80 $p \leq 0.01$
Using both defined criteria, and relation to advantages and disadvantages	17.16	26.90	

The results depicted in Table 8 can be rationalized in terms of the slow shift, from disciplinary teaching at the undergraduate level to an interdisciplinary, HOCS-oriented learning in the upper graduate level. Given the contemporary emphasis in the teaching on 'knowing', one cannot expect meaningful advances from the LOCS level to the realm of HOCS.

8. Conclusions and Implications

Given that science teaching in secondary and tertiary education is still largely taught in a disciplinary orientation (*i.e.*, biology, chemistry, physics) and, similarly, in the teaching of technology, engineering and SSSEE courses, the slow LOCS-to-HOCS paradigm shift constitutes a major area of concern, particularly in respect to "sustainability thinking".

As described earlier (Section 5), the same research methodology was applied in the three research studies and the results presented in this paper; that is, a pre-post design with experimental and control classes and pre-post administration of questionnaires which were similarly assessed and graded, based on the LOCS-HOCS categorization of the research population responses and accompanied by semi-structured interviews with the students and science teachers involved.

The conclusions and implications with respect to the DM study (below) are applicable to all the research results presented in this feature paper.

The DM study, focused on the cognitive aspects of DM in the context of science teaching, aiming at getting an insight into the related HOCS/LOCS-level performance of the decision-maker student, while

being engaged in a DM-related learning [30–34]. Recent research work related to the DM activity indicates that HOCS operations are extensively used during a DM-related inquiry, while LOCS operations are less used during such activities. It also suggests that the DM competence increases with respect to years of education [35] which is congruent with our research-based conceptualization of the development of students' HOCS capabilities [9,18,19,23–25]. Thus, the LOCS/HOCS levels of the questions asked were significantly in favor of the MA students (Table 7), possibly, partially due to the STES-orientation of the MA course, compared to the traditional LOCS-orientation in the science courses at the undergraduate level [9]. Both undergraduate and MA science students appear to be rather similar in their combined capabilities of making or not making a decision. This result suggests that the students were moderately willing to and capable of providing the relevant rationalization for the decisions they made. This means a positive shift in their cognitive rationalization capability in the MA level. Since *the complexity level* of the students' explanations and justifications favored the MA class, suggesting that the MA students' DM capability is higher compared to that of the students in the undergraduate courses.

Our findings corroborate the claimed gap between the rhetoric and philosophy of "STESEP education" and education for 'sustainability thinking' at all levels as well as in the reality of science education practice in K-12 schooling [33] and higher education [34]. Table 9 summarizes freshmen's views concerning 'HOCS questions' included in examinations.

Table 9. Students' (*N* = 47) views of HOCS-type problems [19].

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

In summary: our results suggest that promoting the DM capability via an appropriate HOCS-promoting framework of teaching and assessment has the potential of achieving students' "HOCS learning" [14]. Accordingly, our recommendation is that research-based interdisciplinary HOCS-STESEP-oriented courses and curricula will be implemented in different contexts and settings of SSSEE in primary, secondary and tertiary levels, for the advancement of students' DM and related HOCS, for the advancement of "sustainability thinking" [31–34].

HOCS capabilities are enhanced via (a) tandem implementation of "HOCS- promoting" *teaching strategies* and *assessment* methodologies; (b) such an enhancement requires time and is not achievable via a single-shot, short exercise; (c) the assessment needs not only to be consistent with the teaching objectives, but also ensure the students "sustainability thinking" capability in STEPES contexts and HOCS-promoting instruction; and (d) implementation of the corresponding HOCS-level assessment is essential and attainable, thus suggesting that HOCS development is *contextually*, but not disciplinary contently-bound. Thus, HOCS enhancement not only can be done, it should be done. Yet, a crucial issue is how to do it?

Selected research-based HOCS-promoting teaching strategies follow [5,14,15,21,23,30,34,35]:

(1) Self-study of pre-class lecture "material". Students have the course outline, scheduling, objectives, requirements and assignments in their hands and they study/learn the relevant "material" *before* it is 'covered' in the class, where they bring *their* questions for discussion.

(2) No specific assigned course textbook(s). Students are provided, at the beginning of the course, with a list books and learning sources from which they can choose texts and reference books to use for their study and learning of any relevant topic as they find appropriate for their needs. (This is a kind of the 'guided design' methodology).

(3) Homework assignments—mainly *problems* (not exercises) which require HOCS for their resolution. These problems are to be worked out by the students (preferably in groups) and submitted, *individually*, for feedback and grading by the teachers/professors, teaching assistants, former "graduates" of these courses, in tertiary education and SSSEE teachers in secondary education.

(4) Students' self-assessment: Students self-assess their home assignments, pre-guided by the course teacher/professor [5,14,15,30]. Several relevant examples of these research-based strategies and methodologies, in the contexts of both secondary and (undergraduate) tertiary levels, have been published. Their application in "STESEP education" towards "STESEP Sustainability Thinking" in different education systems, contexts and societies is highly recommended. It can be and, therefore, *should* be done purposely and persistently.

Appendix

The (Pre-) Evaluative Thinking Questionnaire (ETQ)—Selected Items (Applied in the ET-Related Research).

Carefully read the following paragraph:

Water, Man and the Environment

Israel is a semi-arid country, with relatively little precipitation and limited water resources. Because yearly water consumption greatly exceeds the amount that Israel's three main water sources can be renewed (through rainfall), Israel finds itself with a severe water "overdraft" resulting in decreased water levels in all reservoirs. As water levels drop below the red line, water quality and quantity become poorer due to calcification contamination.

A1. After reading the above passage, formulate two thought-provoking questions, which do not have definitive answers, and which you think are important concerning the issue dealt with. Explain how you think each question will contribute to the relevance of the topic.

First question: The answer to this question contributes to the topic by …

Second question: The answer to this question contributes to the topic by …

A2. Using the questions from Section A1, above:

A2.1. Which question, in your opinion, requires further research in order to fully answer, and which doesn't require further research or knowledge.

A2.2. Explain and justify your answer to each of the questions.

A3. The amount of any family's water consumption depends, among others, on their daily habits. Many liters of water can be conserved if simple conservation habits are adopted. Here are some suggested ways to conserve water:

(a) Watering the garden in the evening or at night, to avoid wasted water as a result of evaporation.
(b) Adjusting the laundry machine's water level according to the quantity of laundry to be washed.
(c) Installing a "dual-flush" toilet, which enables choosing the amount of water for flushing depending on the need.
(d) Installing metal or plastic water-saving devices on the taps at home, which ensure an even and constant flow of water.
(e) Drinking bottled mineral water.

A3.1. Examine each of the suggestions (a–e) above, and choose two. Explain if, how, and to what extent each one contributes to the conservation of water.
A3.2. Do you think there are any suggestions above that do not relate to the subject of the passage? If so, explain why.
A3.3. Make a suggestion of your own in which will encourage water conservation.

A4. The title of the passage, "Water, Man and the Environment", includes the word "environment" even though there is no direct reference to the environment within the passage. In your opinion, is there any connection (one or more) between conserving water and the quality of the environment? Justify your answer, whether you think there is a connection or not.

A5. Assuming that that presented in the passage is a reliable indicator of today's situation:

A5.1. Do you think that the passage enables readers to make a personal decision regarding their future behavior regarding consuming and conserving water? Justify your answer whether it is "positive", "negative", or "neutral".
A5.2. In your opinion, what is the main aspect that might influence a person's future behavior with respect to the topic discussed in the passage? Elaborate.

A6. Do you think that an entire chapter entitled "Water, Man and the Environment" should be included (in the relevant textbook) in the high school curriculum? Justify your answer for or against, using at least two criteria.

Conflicts of Interest

The author declares no conflict of interest.

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