**Problem-Based Learning (PBL) for Higher-Order Cognitive Skills (HOCS) Promotion in High School Science Teaching**

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**Abstract**

This study focused on the pre-post enhancement of secondary school science students' problem solving capability via problem-based learning/higher-order cognitive skills-based learning compared to that in the traditionally learning control group. The research was based on a sample of 213 10th grade science students ($N\_{experimental}=104$,$ N\_{control}$=109) in the Arabic sector of the Israeli multisectoral educational system. The initial pre-problem solving capability of both groups, was rather low, but increased differently, during the school year, in favor of the experimental groups with respect to the student's higher-order cognitive skills level, meaning higher problem solving capability in the post compared to the pre. In contrast, the problem solving capability in the pre and post were found to be the same. The empirical findings emphases of the problem-based learning methodology impact and contribution of students' problem solving capability. These results point to the greater impact of the problem-based learning teaching and learning methodologies on the students' problem solving capability compared to the conventional problem solving enhancement in traditional science teaching.

**Key words** problem solving **.** problem-based learning (PBL) **.** higher-order cognitive skills (HOCS) **.** science education – learning – assessment

**Introduction**

There is a wide consensus among science educators concerning the importance of the teaching, learning and assessment of students' PS capability in science education at all levels (Huffman 1997; Milbourne and Wiebe 2017; Pedersen and Liu 2003). Problem, not the conventional algorithmic exercise-solving is considered to be a fundamental issue in contemporary science education (Randles and Overton 2015). However, PS usually refers to an algorithmic problems/questions which, in essence, have just one *correct* answer. In the Israeli multisectoral educational system, particularly in the Arab sector, the teaching is mainly focusing on the transfer of knowledge, which, as such, contributes very little to the development of the students' Higher-Order Cognitive Skills(HOCS) capabilities (Zoller 1993; Zoller and Scholz 2004; Markic et al. 2016). Significantly, the science teachers involved in this research lacked the pedagogical knowledge of "HOCS teaching" and, consequently, felt insecure in teaching beyond the traditional knowledge-based methodology. Consequently, there is a gap between theory and practice.

Educational systems, at all levels, are perceived by students, teachers, parents, organizations and the public at large, to be a teaching frameworks the function of which is to promote the students' learning on the basis of "passing" knowledge-based tests. Weighted scores of these tests are the only, or the main criterion, of the students' achievement in the subject(s) learned. Solving a problem, in this context, is conceptualized by both-teachers and students as the providing just a single algorithmically *correct* answer(s) to the problem(s) at point. In contrast to the conventional algorithmic-based teaching, learning and assessment in science education, the non-algorithmic HOCS-based critical thinking, evaluative thinking, system thinking, decision-making and problem solving (Zoller 1993; Zoller and Levy Nahum 2012). A major driving force behind the current effort to reform science education is the convection of many that it is so important and essential to nurture and develop students' HOCS, which will help and enable them to function more actively, meaningfully and significantly in the (changing) society and to better act in the daily life. In order to that, it requires appropriate practice-oriented research-based teaching strategies and assessment methodologies.

**Conceptual Framework**

**Problem Solving (PS) and Problem-Based Learning (PBL)**

The process of problem solving involves a composite activity of cognitive, operative and effective variables, which are dependent on the number and quality of available operative schemata (Stamovlasis and Tsaparlis 2005). Researchers agree that: (a) the context of the problem solving is a critical determining factor in the process (Raine and Symons 2005); and (b) by the application of appropriate and relevant teaching strategies, the improvement of students' PS capability is attainable (Zoller and Levy-Nahum 2012). The PBL pedagogical approach was shown to be an effective teaching strategy for encourage students to develop their transferable, PS, and teamwork skills (Warnock and Mohammadi-Aragh, 2016; Wong and Day 2009). Thus, PBL constitutes a pedagogical approach that challenges science students to solve non-algorithmic problems which have more than just one "correct" (algorithmic) solution. Dealing with such problems requires the HOCS capabilities of critical, system and evaluative thinking as well as related others (Zoller 2015; Levy Nahum et al. 2010) and creativity (Birgili 2015).

Studies have shown that PBL has the potential to develop both-- the HOCS capabilities and an motivation for learning (Strobel and van Barneveld 2009) and literacy skills (Shults and Li 2016), as well as the promotion of students' *transfer* capabilities (Overton and Randles 2015). Senocak, Taskesenligil and Sozbili (2007) showed that there was statistically significant difference between the experimental and the control groups in their attitude toward chemistry that the PBL learning has a significant impact on the development of students’ skills, such as self-directed learning, cooperative learning and critical thinking.

In contrast to the "traditional" teacher-centered factual knowledge which, not necessarily is related to authentic life problems, PBL is a student-centered teaching methodology which is applied in the science education context (Etherington 2011; Gallagher et al. 1995). As such, PBL puts the students in the center, so that they become actively involved throughout the learning process while the teachers keep acting as facilitators (Baran and Solzbilir 2017). Ultimately, the PBL active learning methodology has the potential of preparing students for lifelong learning (Leite, Dourado and Morgado 2015).

Non-algorithmic problems solving requires the development of students' HOCS (Zoller 1993; 2012; 2015). PBL helps students not only to acquire algorithmic knowledge, but also develop their own capability to solve non-algorithmic problems. In summary: PS is a central HOCS capability; its development and nurturing is expected to lead students from learning to know to learning to think in science education, and beyond (Zoller 2015).

**Higher-Order Cognitive Skills (HOCS)**

The acquisition, development and nurturing of students' non-algorithmic PS capability in science, technology, environment, society (STES)/STEM and science, teaching, environment, society, economy, policy (STESEP) education, constitute a major goal in science education, by science educators worldwide (Stamovlasis et al. 2005). Teaching, learning and assessment of HOCS capabilities requires alternative methods of teaching which, in turn, are linked to the required training of science teachers with respect to the ways and objectives of teaching science in the present era (Overton and Randles 2015). PBL is directly relates to the PS component in the conceptual model of HOCS (Zoller 2015).

**Research Question**

The research question has been targeted on determination (quantitatively and qualitatively) whether will there be a pre-post progress in the PS capability in the experimental group students based on PBL and HOCS promoting teaching and learning, guided by the following question:

* Is there a statistically significant difference in the PS capability of students in the experimental PBL-based group compared to those in the traditional teaching control group?

**Methodology**

**Research Population, Procedures and Design**

The research population consisted of 213 10th grade students (female 53%; male 47%) in 3 schools of the Arabic sector, in the northern part of Israel. In each school, one class was the experimental group (PBL-HOCS) ($N=104$) and the other was the control (traditional approach) ($N$=109). 2 experienced biology teachers (female and male) taught the 2 groups in the 6 classes of the 3 schools; each in the control and the experimental class at the same school. One of those teachers has a seniority of 16 years and the other 19. Both have a master's degree in science education. It is important to note that these teachers received training in PBL from the researcher and were closely monitored to implement intervention strategies throughout the study.

The PBL-based pre-post-intervention and the control traditional teaching were pursued during one school year in 10th grade classes of secondary schools. The main teaching and assessment strategies applied in the PBL classes were: *case studies, question asking and mini projects.*

**The Model of PBL-based Teaching and Learning of in the Experimental Group**

It is important to emphasize that despite the advantages of the PBL method, previous studies (e.g. Herreid 2003; Ribeiro 2011; Wood 1994; Wong and Day 2009) have shown some shortfalls to this method. Implementation of PBL requires commitment, dedication of time, great effort, lots of preparation. These studies come to the conclusion that a considerable resistance is to be expected when beginning to develop PBL in science education or other areas. Wong and Day 2009 suggesting an Assessment of short and long-term outcomes to demonstrate that the teaching method is achieving its goals for students is needed to reassure stakeholders that the effort devoted to PBL is worthwhile. In this study, In order to bring about the success of the intervention and the advancement of the subject, a thorough preparation was made and cooperation from both teachers and students was demanded.

The PBL model relates to planning the teaching process and organizing the lesson, selecting the problems around which the learning will be organized, preparing the learning materials and teaching, defining the roles of the teacher and the student, and evaluation of students' achievements.

The main characteristics of teaching in this model are: the problems faced by the students are problems of daily life that invite an authentic solution as possible; the issues and concepts involved in solving the problem are related to several disciplines; group working; The role of the teacher is to guide the groups and to promote their work and to be an expert; This model requires collecting information and learning new concepts and topics. The student must identify the knowledge he needs and use additional sources to acquire this knowledge. Developing lesson plans using the PBL method required the following steps:

1. Identifying the learning outcomes in relation to learning objectives: content and knowledge in the topics studied, skills for problem solving, HOCS, and social skills.

2. The definition of the student's assessment method refers to the definition of the products to be tested, and problem solving capabilities, the definition of the evaluation tools, and the criteria and grades for each criterion.

3. Problems planning: A problem should include some characteristics - was pumped from the real world; An open problem that has no unequivocal solution; A problem that requires self-learning; A problem that requires teamwork; Dealing with it enables the attainment of educational goals and the development of problem solving capabilities; Based on previous knowledge and experience but whose solution requires the self-learning of new material. Steps to problem planning:

• Defining the specific learning objectives to be achieved through the problem (discipline knowledge, problem solving capabilities, and HOCS).

• Formulation of the problem, including details of the expected difficulties.

• Examining the problem - whether the problem enables the achievement of specific educational goals - adapting the problem as needed.

• Adding possible sources of information.

• Preparation of appropriate reference materials.

4. Planning the teaching system: in this set of lessons, the meetings planned in such a way as to enable the students involved the problem solving to work individually and in groups. Time allocated to discussions with the teacher in the plenum (classroom) and evaluation of intermediate products. They also provided tools for collecting and processing information.

5. Implementation: at this stage, the purpose and the required products were described, the method of work and division into groups, the evaluation method and the timetable, and define the roles of the student and the teacher. In the relevant professional-educational literature, there is evidence that the cultivation and development of HOCS capabilities, including students problem solving, can be achieved by the following such strategies and methods: Teaching-learning combines case-studies; questions asking capability; teaching-learning combines mini projects (Overton and Randles 2015; Savery and Duffy 1995).

In the control group, conventional instruction methods were used. Those methods are a teacher-centered where students most of the time are passive audience. Most of the lessons were conducted in the form of a lecture in which the teachers stood face to face in front of the class and presented the material with the help of pen and board, combining a few questions and answers and discussion segments. Sometimes the teachers used a presentation and video. At the end of the lesson, the teachers usually gave exercises as homework from the reservoir of questions at the end of the chapter in the book. The main lessons in this method focused on information transfer.

**Research Procedure**

The pre and post PBL-HOCS research questionnaires were self-developed (see appendix 1) .Those questionnaires were administered to both the experimental and control groups. The questionnaires were validated, prior to their administration, by 4 experts who examined their suitability with respect to their structure and content validity. The results indicated a high percentage of consensuses among the experts -- 90.5% and 85.4%, respectively. Each questionnaire consisted of 8 open-ended HOCS-oriented questions/issues to which the students were asked to respond. For both--pre and post questionnaires the reliability of acceptable internal traceability ($∝\_{cronbah})$ were found to be 0.681 and 0.676, respectively.

**Scoring Methodology and Data Analysis**

**Testing, scoring methodology and correlation between the evaluators**

The students' responses were scored by 3 evaluators for determining the Inter-Rating 0, 1, 2 as follows:

* No response, or irrelevant one scored zero points (0).
* A lower-order cognitive skill (LOCS) level response scored one point (1).
* A HOCS level response scored two points (2).

A LOCS level response is an algorithmic, simplistic-trivial and/or one-dimensional. The LOCS range is characterized by an algorithmic knowledge level questions, whose responses or solutions require just a primarily recall, or application of a theory and/or known to the student knowledge within known situations and contexts. On the other hand, HOCS level requires beyond one "correct" response, reference unequivocal or one-dimensional and is based sometimes, on other HOCS capabilities like system thinking, critical thinking, evaluative thinking, creative thinking, problem solving, decision making, and of course the capability to transfer (Tsaparlis and Zoller 2003). It also includes the application of a known theory or unusual situations Knowledge and strange for the student- responder. Student's response(s) on a HOCS level scored 2; meaning that the PS capability of the responding student is within this level.

The following are examples of students' responses and their scoring: (0), 1 (LOCS) and 2 (HOCS).

**Selected Students' Responses (for the same item):**

The item (from post questionnaire): "A chemical factory was established in a certain city; some of the raw materials used there have a potential undesirable biological impact. Ultimately, at the end of the chemical process, the residuals reach the river near the factory. The factory provides work to many city residents in which the unemployment rate is high. On the banks of the river there is a public park where the city residents spend vacations and holidays. The mayor had received several suggestions for solving the problems created by the factory's sewage.

If the mayor would consult with you, what would you suggest to him to do-- in order to solve the factory's sewage problem(s)? Explain your response.

* Response score (0):

- Student response: *How does the factory affect the river?*.

This response was assessed as irrelevant because it is doesn't address the problem which presented to him: The student makes no suggestion to the mayor to solve the problem created by the factory.

* Response score 1 (LOCS):

- Student response: *close the park and not walk*.

This response is simplistic and algorithmic. This was assessed as a trivial knowledge-level response.

* Response score 2 (HOCS):

- Student response: *Not to close the factory because it will exacerbate the problem of unemployment in the city, but instead, to move it to another location far from the park, but-- not too far from the city, in order to continue employing the city residents, and yet, the problem of toxic substances produced by the factory must be solved*.

This response was scored 2 (HOCS level) since the student is dealing here with contradictions within a complex, non-algorithmic and multi-component system. **Agreement among evaluators**

In order to verify the evaluation of the three evaluators, the degree of agreement between the evaluator 1 and each of the two other evaluators- 2 and 3 was examined in both the pre and post questionnaires. This done by comparing the number of responses (from 8) which scored by evaluator 1 as HOCS in the pre/post questionnaire and the number of responses scored by evaluator 2 as HOCS in the pre/post questionnaire. The same thing was done to compare the number of responses scored by evaluator 1 as HOCS in the pre/post questionnaire and the number of responses scored by evaluator 3 as HOCS in the pre/post questionnaire. In order to carry out the above tests, the Intra-Class Correlation coefficient (ICC) was used. Table 1 below presents the data:

**Table 1** Agreement between the evaluation of evaluator 1 and the evaluation of each of the 2 evaluators- 2 and 3 in each of the two questionnaires

|  |  |  |  |
| --- | --- | --- | --- |
|  | ICC | The comparison | Questionnaire |
|  | 0.931 | evaluator 1- evaluator 3 | pre |
|  | 0.972 | evaluator 1- evaluator 2 |
|  | 0.951 | evaluator 1- evaluator 3 | post |
|  | 0.969 | evaluator 1- evaluator 2 |

$$ \*\*\*p<0.001$$

In summary: there is agreement between the evaluation of evaluator 1 and evaluator 2 and 3 for the number of responses (from 8) that were scored as "HOCS responses" to the both questionnaires: pre and post.

**Students' "distribution" on the LOCS / HOCS levels**

As stated, the study was conducted by qualitative analysis of student responses to the questionnaires (pre-post) and a statistical analysis of the levels of responses after they were scored (in accordance with the above). The students were asked to respond to 8 items in each questionnaire. The study population was classified according to the number of responses at the HOCS level only:

• Students who responded to 0-2 questionnaires' items (out of the total 8) on the HOCS level, were rated as "LOCS students";

• Students who responded to 3-5 questionnaires' items, on the HOCS level, were rated as "mixed LOCS-HOCS students"; and -

• Students who responded to 6-8 questionnaires' items, on the HOCS level, were rated as "HOCS students".

The criteria for determining the "LOCS students", "mixed LOCS-HOCS students" or "HOCS-student" categorization was agreed upon by evaluators who assessed the questionnaire, in accord with the previously established categorization (Tsaparlis and Zoller, 2003).

**Results**

**Table 2** The pre-post percentage distribution of the students' responses on the HOCS levels 0, 1, 2

|  |  |  |
| --- | --- | --- |
| Control | Experimental |  |
| 2 | 1 | 0 | 2 | 1 | 0 |  |
| 12.0 | 79.4 | 8.6 | 11.9 | 80.5 | 7.6 | Pre |
| 15.0 | 77.5 | 7.5 | 19.2 | 74.9 | 5.9 | Post |

There was a positive change in both groups – experimental and control. However, in spite of the positive increase in score 2, which reflects responses at the HOCS level, these initial values show low achievement on the HOCS level. Table 3 presents the percentage frequency of 'the number of responses out of 8' that were scored as responses in the HOCS level in each of the pre and post in the experimental group (PBL-HOCS), and the control group (traditional-algorithmic approach).

**Table 3** Distribution of the HOCS levels in the experimental and control groups

|  |  |  |
| --- | --- | --- |
| Post | Pre |  |
| Frequency (%) | Frequency(%) | Number of responses at the HOCS level | Group |
| 40.4 | 55.8 | 0 |  |
| 21.2 | 19.2 | 1 |  |
| 14.4 | 9.6 | 2 |  |
| 10.6 | 10.6 | 3 | Experimental |
| 3.8 | 1.9 | 4 |  |
| 1.9 | 0 | 5 |  |
| 7.7 | 2.9 | 6 |  |
| 47.7 | 61.5 | 0 |  |
| 13.8 | 5.5 | 1 |  |
| 22 | 17.4 | 2 |  |
| 9.2 | 10.1 | 3 | Control |
| 4.6 | 3.7 | 4 |  |
| 0 | 0 | 5 |  |
| 2.8 | 1.8 | 6 |  |

From the table, we can see that no one of the two groups - experimental and a control - did not provide HOCS level responses on all the 8 items in the pre and post questionnaires. The number of responses at the maximum HOCS level for students in both groups was only 6. Further review shows that the distribution of the students' responses on the HOCS level indicates a higher advantage of the experimental group. Using the data in the above table, the estimated proportion of students classified according to one of the three student's "LOCS-HOCS" levels was calculated, for both questionnaires in each of the two study groups. The results are presented in table 4.

**Table 4** The distribution of each of the three "LOCS-HOCS" levels in the experimental and control groups

|  |  |  |  |
| --- | --- | --- | --- |
| Post | Pre | Level | Group |
|  |  |
| 0.760 | 0.846 | "LOCS students" |  |
| 0.163 | 0.125 | mixed LOCS-HOCS students" " | Experimental |
| 0.077 | 0.029 | "HOCS students" |  |
| 0.834 | 0.844 | "LOCS students" |  |
| 0.138 | 0.138 | mixed LOCS-HOCS students" " | Control |
| 0.028 | 0.018 | "HOCS students" |  |

The "LOCS students" level in the experimental and the control groups, in the pre questionnaire, is essentially the same; 0.846 and 0.844, respectively. There is no significant difference between the "mixed LOCS-HOCS students" levels in the experimental (0.125) and the control group (0.138). However, there is no significant difference in the "HOCS students" level in the experimental group (0.029) and the control group (0.018). Significantly, the "LOCS students" proportion is the highest in both--the experimental and the control groups. In the post questionnaire, there are no significant difference between the experimental and the control group in the "mixed LOCS-HOCS students" level, and the "LOCS students" levels; 0.760 and 0.834, respectively. The "mixed LOCS-HOCS" level in the experimental group is 0.163, compared with essentially the same level, 0.138 in the control group. The proportion of the "HOCS students" level in the experimental group is 0.077, the same level in the control group -- 0.028. Interestingly, this "LOCS students" level is the highest in each of the 2 study groups. In the transition from the pre -to- post, an insignificant improvement, in the "HOCS student" level of the experimental group, was observed, with increasing by 0.048. In contrast, this level in the control group increased by 0.01.

The research question was examined by the application of the Generalized Estimation Equation (GEE) test, while comparing the distribution of the student's HOCS level in the pre and post. The variables used in the GEE application were: the dependent variable ("HOCS students" level); the intra-test variable (stage of the research) and the independent variable (teaching-learning-assessment method). This question was examined in two stages: in the first, GEE was used, to reveal if there is a gap between pre and post in problem solving. The following table summarizes the test results (the table contains, the estimates of the coefficients of the linear model (b), the Odds Ratio (OR), and the confidence interval at 95% confidence level for OR).

**Table 5** GEE test to examine the relationship between research stage and PS

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | $$95\%CI for OR$$ | $$OR$$ | $$b$$ |  |
|  | $$2.086-5.463$$ | $$3.913$$ | $$1.364$$ | LOCS relative to HOCS |
|  | $$11.477-14.637$$ | $$21.86$$ | $$3.085$$ | LOCS-HOCS relative to HOCS |
|  | $$0.54-0.935$$ | $0.71$ | $$-0.342$$ | The stage of the research (pre relative to post) |

$$\*p<0.05, \*\*\*p<0.001$$

The pre-post odds ratio in connection with the student's "HOCS level for problem solving" (OR=0.71) was significant at the 0.05 significance level. The meaning of the result is that the ratio for being on higher scales than being at the lower of the student's HOCS level in the post is $\frac{1}{0.71}$ that is 1.41 than the same ratio in the pre. It can be concluding that the chance of obtaining results on higher level (HOCS vs. LOCS and/or LOCS-HOCS, HOCS and/or LOCS-HOCS vs. LOCS) is higher in the post than in the pre. Table 6 presents the changes in the proportions of each level in the transition from pre -to- post.

**Table 6** Proportion estimates () for each of the 3 student levels in pre-post

|  |  |  |
| --- | --- | --- |
| Post | Pre | Level |
|  |  |
| 0.798 | 0.845 | "LOCS students" |
| 0.15 | 0.132 | "mixed LOCS-HOCS students"  |
| 0.052 | 0.023 | "HOCS students" |

After finding a difference in the PS capability between pre and post, the GEE test was applied (again) in order to check whether the teaching, learning and assessment method is a source of this difference. The following table summarizes the results.

**Table 7** The relationship between the research stage and PS capability

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | $$95\%CI for OR$$ | $$OR$$ | $$b$$ |  | Group |
|  | $$1.994-4.872$$ | $$3.117$$ | 1.137 | LOCS relative to HOCS |  |
|  | $$6.447-29.832$$ | $$13.686$$ | 2.630 | LOCS-HOCS relative toHOCS | Experimental |
|  | $$0.347-0.903$$ | $$0.56$$ | -0.580 | The stage of the research (pre relative to post) |  |
|  | $$3.035-8.343$$ | $$5.032$$ | 1.616 | LOCS relative to HOCS |  |
|  | $$12.481-134.755$$ | $$41.011$$ | 3.714 | LOCS-HOCS relative toHOCS | Control |
|  | $$0.739-1.16$$ | $$0.926$$ | $$-0.077$$ | The stage of the research (pre relative to post) |  |

$$\*p<0.05, \*\*\*p<0.001$$

Among the experimental group, the pre-post odds ratio in connection with the "student HOCS level in problem solving" (OR = 0.56) was *significant* . For this group, the ratio for being on higher than lower levels of the students' HOCS level in post was $\frac{1}{0.56} $that is 1.78, than the same ratio in pre. It can be conclude that, in the experimental group, the chance of obtaining results on higher levels (HOCS vs. LOCS and/or LOCS-HOCS; HOCS and/or LOCS-HOCS vs. LOCS) are higher in post than in pre. Table 3 shows that, despite the fact that the LOCS level remained the highest in the post (0.76), the student LOCS level for this group decreased in the post by 0.086 (compared to their proportion in the pre), in contrast to increase in the LOCS-HOCS and HOCS levels (in post compared with the pre) by 0.038 and 0.048, respectively. Among the control group, there is no connection between the research stage with the "student HOCS level in problem solving" i.e. a *non-significant* difference. This is expressed in the odds ratio between the post and the pre of "HOCS students" level in PS, which is very close to 1 (OR = 0.926). The meaning of the result is: For this group, the chance of obtaining results on higher levels (HOCS vs. LOCS and/or LOCS-HOCS, HOCS and/or LOCS-HOCS vs. LOCS) in the post are the same as in the pre.

**Discussion and Conclusions**

This study offers a research-based framework for the development, implementation and evaluation of PS, thus serving as an important component for promoting HOCS.

An important challenge for today's education, in all education settings, is the development and implementation of instructional practices that will foster students' skills for solving complex interdisciplinary, real world problems (Randles and Overton 2015). Our study, provides some insights into the way that HOCS-promoting problems, may be constructed, categorized and graded, as well as, into the multifaceted ways that student solve them.

The most important research based result of this study is that the initial PS capability (post-pre) improved over time in the experimental and control groups, significantly more in the experimental PBL group. These findings reinforce the researchers' assumption that exposing students to PBL and HOCS-based teaching and learning strategies will result in the development of their PS capability. These findings suggest that PS can be developed via different teaching-learning and assessment strategies, in line with the findings of others (Warnock and Mohammadi-Aragh 2016; Overton and Randles 2015).

Our research-based findings show that the PBL-based treated students have significantly improved their PS and HOCS skills. These findings constitutes an empirical evidence of the PBL effectiveness in students' science learning. In a related study, Ferreira and Trudel (2012) reported that students' pointed on: (1) greater peers interaction that PBL supports and strengthens; (2) A greater sense of control over their studies that PBL promotes. On the other hand, traditional-algorithmic-based teaching (control group) lacked these components as well as system and critical thinking which are based on rational decision-making and PS (Zoller and Scholz 2004). Traditional teaching, however, primarily involves a good memorization of knowledge (Barak, Ben-Chaim and Zoller 2007; Ivic, 2016). Therefore, student skills, critical thinking, problem solving and preparation for lifelong learning cannot be developed. Ivic (2016) asked himself "why the traditional work method still prevails in Croatian schools. Although modern teaching strategies are often written about in didactic literature and in the media for the purpose of their promotion, this research has unfortunately proven that they are rarely applied in most schools. The reason may be a strictly written curriculum, inflexible time table, especially in subject teaching, methods of assessing teaching outcomes which are still adapted to traditional teaching style or insufficient education of teachers who may not know or may not want to do things differently and consciously resist to changes a modern society imposes". I think that the present study can also claim similar things, according to its conclusions.

Zoller and Levy Nahum (2012) concluded that if teachers apply HOCS-promoting teaching strategies, such as case studies, application of mini projects, class discussion of real world problems, encouragement of open-ended discussions, which have more than one "correct" conclusion and the promotion of research-oriented experiments, then there is a good chance of developing and nurturing students' HOCS capabilities. Similarly, case study, for example, has been found to contribute to the development of HOCS and PS. This finding reinforces the findings of Herried (1997), which combined case studies with several science courses over 4 years and found that this strategy encouraged learning in action, developed analytical, critical thinking and decision making, while dealing with complex problems.

In conclusion: Our research results point at the greater impact of the PBL/HOCS-based teaching-learning methodology on the enhancement of high school science students' PS capability in framework of the "traditional" science teaching and learning for helping students to develop their HOCS capability and thus strengthen their conceptual understanding of science.

**Acknowledgement** This research was partially supported by The MOFET Institute and the Department of Teacher Education at the Ministry of Education in Israel.

**Appendix 1 (Problem Solving Questionnaire - Selected items)**

1. Water shortage, which is an essential resource, constitutes one of the main problems of Israel .
2. In your opinion, what is needed in order to solve, even partially, the water shortage in Israel? explain your suggestion.
3. Is your proposal in (a) above, the only way, or there are other possible ways? Explain.
4. The issue of organ donation and its medical and human importance is well known, especially now when there is a severe shortage of organ donations.
5. Suggest possible way(s) to solve the shortage problem.
6. Offer a possible solution, of your own, in order to raise the public awareness for the purpose and the importance of organ donation?
7. Suggest a PROBLEM (personal, public, economical, educational, technological, scientific...) that you would like and/or find to be a possible solution. Explain: Why do you think that the problem you presented is meaningful?

**References**

Baran, M., & Sozbilir, M. (2017). An application of context- and problem-based learning (C-PBL) into teaching thermodynamics. *Research in Science Education*, https://doi.org/10.1007/s11165-016-9583-1.

Barak, M., Ben-Chaim, D., & Zoller. (2007). Purposely teaching for the promotion of higher-order thinking skills: A case of critical thinking. *Research in Science Education, 37*(4), 353-369.

Birgili, B. (2015). Creative and critical thinking skills in problem-based learning environments. *Journal of Gifted Education and Creativity, 2*(2), 71-80.

Etherington, M.B. (2011). Investigative primary science: A problem-based learning

 approach. *Australian Journal of Teacher Education, 36*(9), 36-57.

Ferreira, M., & Trudel, A. (2012). The impact of problem-based learning (PBL) on student attitudes toward science, problem-solving skills, and sense of community in the classroom. ***Journal of Classroom Interaction,*** *47*(1), 23-30.

Gallagher, S. A., Stepien, W. J., Sher, B. T., & Workman, D. (1995). Implementing

 problem-based learning in science classroom. *School Science and*

 *Mathematics, 95*(3), 136-146.

Herreid, C. F. (2003). The death of problem-based learning. *Journal of College Science Teaching,* 32, 364–366.

Herried, C. F. (1997). What is a case? Bringing to science education the established tool of law and medicine. *Journal of College Science Teaching, 27*, 92-95.

Huffman, D. (1997). [Effect of explicit problem solving instruction on high school students' problem-solving performance and conceptual understanding of physics](http://onlinelibrary.wiley.com/doi/10.1002/%28SICI%291098-2736%28199708%2934%3A6%3C551%3A%3AAID-TEA2%3E3.0.CO%3B2-M/full). *Journal of Research in Science Teaching, 34*(6), 551–570.

Ivic, S. (2016). Frequency of applying different teaching strategies and social teaching Methods in primary schools. *Journal of Education and Practice*, *7*(33), 66-71.‏

Leite, L., & Dourado, L., & Morgad, S. (2015). Sustainability On Earth” webQuests: Do they qualify as problem-based learning Activities?. Research in Science Education, 45(1):149–170.

Levy Nahum, T., Azaiza, I., Ben-Chaim, D., Herscovitz, O., Zoller, U. (2010). Does STES-oriented science education promote 10th-grade students’ decision capability? *International Journal of Science Education*, 32(10), 1315-1336.

Markic, S., Eilks, I., Mamlok-Naaman, R., Hugerat, M., Kortam, N., Dkeidek, I., & Hofstein, A., & (2016). One country, two cultures – A multi-perspective view on Israeli chemistry teachers` beliefs about teaching and learning. *Teachers and Teaching: Theory and Practice,* 22(2), 131-147.

 [Milbourne](https://link.springer.com/search?facet-creator=%22Jeff+Milbourne%22), J., & [Wiebe](https://link.springer.com/search?facet-creator=%22Eric+Wiebe%22), E. (2017). The role of content knowledge in ill-structured problem solving for high school physics students. [*Research in Science Education*](https://link.springer.com/journal/11165)*,* 1-15. <https://doi.org/10.1007/s11165-016-9564-4>.

Overton, T., & Randles, C.A. (2015). Beyond problem-based learning: Using dynamic PBL in chemistry. *Chemistry Education Research and Practice, 16*(2), 251-259.

Pedersen, S., & Liu, M. (2003). The transfer of problem-solving skills from a problem-based learning environment: The effect of modeling an expert’s cognitive processes. *Journal of Research on Technology in Education*, *35*(2), 303-320.

Raine, D. J., & Symons, S. L. (2005). *PossiBiLities: A practice guide to problem based learning in physics and astronomy*. Higher Education Academy, UK Physical Sciences Centre.

[Randles](http://pubs.rsc.org/en/results?searchtext=Author%3AC.%20A.%20Randles), C. A., & Overton T. L. (2015). Expert *vs.* novice: Approaches used by chemists when solving open-ended problems. *Chemistry Education Research and Practice, 16*(4) 811-823.

Ribeiro, L. R. C. (2011). The pros and cons of problem-based learning from the teacher’s standpoint. *Journal of University Teaching & Learning Practice*, *8*(1), 4.‏

Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. *Educational Technology*, *35*(5), 31-37.

Senocak, E., Taskesenligil., Y., & Sozbili, M. (2007). A study on teaching gases to prospective primary science teachers through problem-based learning. *Research in Science Education, 37*(3):279–290.

Stamovlasis, D., & Tsaparlis, G. (2005). Cognitive variables in problem solving: A nonlinear approach. *International Journal of Science and Mathematics Education, 3*(1), 7-32.

Stamovlasis, D., Tsaparlis, G., Kamilatos, C., Papaoikonomou, D., & Zarotiadou, E. (2005). Conceptual understanding versus algorithmic problem solving: Further evidence from a national chemistry examination. Chemistry Education Research and Practice, 6(2), 104–118.

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta synthesis of meta-analyses comparing PBL to conventional classrooms. Interdisciplinary Journal of Problem-based Learning, 3(1), 44-58.

Tsaparlis, G. & Zoller (2003). Evaluation of higher vs. lower-order cognitive skills-type examinations in chemistry: Implications for university in class assessment and examinations. *University Chemical Education*, 7(2), 50-57.

Warnock, J. N., & Mohammadi-Aragh, M. J. (2016). Case study: Use of problem-based learning to develop students' technical and professional skills. *European Journal of Engineering Education, 41*(2), 142-153.

Wong, K. K. H., & Day, J. R. (2009). A comparative study of problem-based and lecture-based learning in junior secondary school science. *Research in Science Education, 39*(5):625–642.

Wood, E. J. (1994). The problems of problem‐based learning. *Biochemistry and Molecular Biology Education*, *22*(2), 78-82.‏

Zoller, U. (1993). Are lecture and learning compatible? Maybe for LOCS: unlikely for HOCS. *Journal of Chemical Education, 70*(3), 195-197.

Zoller, U. (2012). Science education for global sustainability: What is necessary for teaching, learning and assessment strategies? *Journal of Chemical Education, 89*, 297-300.

Zoller, U. (2015). Research-based transformative Science/STES/STEM/STESEP education for 'sustainability thinking': From teaching to "Know"- to Learnig to "Think". *Sustainability*, *7*(4) 4474-4491.

Zoller, U., & Levy Nahum, T. (2012). From teaching to 'know'- to learning to 'think' in science education. In B. Fraser, K. Tobin & D.C. McRobbie (Eds.), *Second International Handbook of Science Education* (Vol. 1, Ch. 16, pp. 209-330). New York: Springer.

Zoller, U., & Scholz, R. W. (2004). The HOCS paradigm shift from disciplinary knowledge (LOCS) to inter disciplinary evaluative system thinking (HOCS): What should it take in Science – Technology – Environment - Society oriented courses, curricula and assessment? *Water Science & Technology, 49*(8), 27-36.