**Problem-Based Learning for the Promotion of Higher-Order Cognitive Skills in High-School Science Teaching**

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**Abstract**

This study focused on the pre-and post-enhancement of high-school science students' problem-solving (PS) capabilities via problem-based learning (PBL)/higher-order cognitive skills (HOCS)-based learning, compared to those of a traditional 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-PS capabilities of both groups were somewhat low. They increased differently during the school year, however, 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 PS capabilities in the pre and post stages were found to be the same. The empirical findings emphasized the impact and contribution of the PBL methodology when it came to students' PS capabilities. These results point to the greater impact of PBL teaching and learning methodologies on the students' PS capabilities compared to conventional PS enhancement in traditional science teaching.

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

**Introduction**

There is a broad consensus among science educators about the importance of the teaching, learning and assessment of students' PS capabilities in science education at all levels (Huffman 1997; Milbourne and Wiebe 2017; Pedersen and Liu 2003). PS, not conventional algorithmic exercise solving, is considered to be a fundamental issue in contemporary science education (Randles and Overton 2015). However, PS usually refers to algorithmic problems/questions for which, in essence, there is only one *correct* answer. In the Israeli multisectoral educational system, particularly in the Arab sector, teaching focuses mainly on the transfer of knowledge. As such, it contributes very little to the development of students' HOCS capabilities (Zoller 1993; Zoller and Scholz 2004; Markic et al. 2016). Significantly, the science teachers involved in this research study lacked the necessary pedagogical knowledge of "HOCS teaching" and, consequently, felt insecure 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 as teaching frameworks geared at promoting students' learning on the basis of "passing" knowledge-based tests. The weighted scores of these tests are the only, or the main, criterion of students' achievements in the subject(s) learned. Solving a problem, in this context, is conceptualized by both-teachers and students in terms of the provision of a single algorithmically *correct* answer(s) to the problem(s) in question. In contrast to conventional algorithmic-based teaching, learning and assessment in science education, 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 conviction of many that it is very important, even essential, to nurture and develop students' HOCS, which will help and enable them to function more actively, meaningfully and significantly in a (changing) society and to behave better in daily life. To achieve this, appropriate practice-oriented research-based teaching strategies and assessment methodologies are required.

**Conceptual Framework**

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

The PS process involves a composite activity of cognitive, operative and effective variables, which are dependent on the number and quality of the operative schemata available (Stamovlasis and Tsaparlis 2005). Researchers agree that: (a) the context of the PS activity is a critical determining factor in the process (Raine and Symons 2005); and (b) through the application of appropriate, relevant teaching strategies, students' PS capabilities can be improved (Zoller and Levy-Nahum 2012). The PBL pedagogical approach was shown to be an effective teaching strategy for encouraging students to develop their transferable, PS, and team-working 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 for which there is more than just one "correct" (algorithmic) solution. Dealing with such problems requires HOCS capabilities of critical, system and evaluative thinking as well as other related ones (Zoller 2015; Levy Nahum et al. 2010) and creativity (Birgili 2015).

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

In contrast to "traditional" teacher-centered factual knowledge, which is not necessarily related to authentic life problems, PBL is a student-centered teaching methodology applied in the science education context (Etherington 2011; Gallagher et al. 1995). As such, PBL places the students at the center, ensuring that they are actively involved throughout the learning process while the teacher continues to act as a facilitator (Baran and Solzbilir 2017). Ultimately, the PBL active learning methodology has the potential to prepare students for lifelong learning (Leite, Dourado and Morgado 2015).

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

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

The acquisition, development and nurturing of students' non-algorithmic PS capabilities in science, technology, the environment, society (STES)/STEM and science, teaching, the environment, society, economy, and policy (STESEP) education, constitute a major goal in science education among science educators worldwide (Stamovlasis et al. 2005). Teaching, learning and assessing HOCS capabilities requires alternative teaching methods 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 related to the PS component of the conceptual HOCS model (Zoller 2015).

**Research Question**

The research question centered on the determination (both quantitative and qualitative) of whether or not will there be pre-and post-progress in the PS capabilities of the experimental group of students based on PBL and HOCS promoting teaching and learning. This was guided by the following question:

* Is there a statistically significant difference between the PS capabilities of students in the experimental PBL-based group and those in the traditional teaching control group?

**Methodology**

**Research Population, Procedures and Design**

The research population consisted of 213 10th-grade students (53% female; 47% male) in three schools in 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) group. Two experienced biology teachers (female and male) taught the two groups in the six classes of the three schools, in both the control and the experimental classes at the same school. One of those teachers had sixteen years’ experience and the other nineteen. Both hold 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 conducted for one school year in 10th-grade classes in high schools. The main teaching and assessment strategies applied in the PBL classes were: case studies; asking questions; and mini projects.

**The PBL-based Teaching and Learning Model 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 revealed certain shortfalls to this method. The implementation of PBL requires commitment, time, a great amount of effort, and considerable preparation. These studies concluded that a considerable amount of resistance is to be expected when beginning to develop PBL in science education or other areas. Wong and Day 2009 suggested that it is necessary to carry out an assessment of short- and long-term outcomes to demonstrate that the teaching method is achieving its goals for students, in order to reassure stakeholders that the effort devoted to PBL is worthwhile. In this study, in order to ensure the success of the intervention and the advancement of the subject, a thorough preparation was carried out 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 students, and evaluating the students' achievements.

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

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

2. Defining the student's assessment method involved identifying the products to be tested, PS capabilities, and defining the evaluation tools and the criteria and grades for each criterion.

3. Problem planning: a problem should include certain characteristics: it is derived from the real world; it is an open problem that has no unequivocal solution; it requires self-learning; it requires teamwork; by dealing with it, it possible to attain educational goals and develop PS capabilities; and it is based on previous knowledge and experience but the solution requires the self-learning of new materials. The steps involved in planning problems comprise:

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

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

• Examining the problem to ascertain whether it allows for the achievement of specific educational goals, and adapting it as needed.

• Adding possible sources of information.

• Preparing appropriate reference materials.

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

5. Implementation: during this stage, the purpose and required products were described, as were the method of work and division into groups, the evaluation method and timetable, and the roles of the student and teachers. In relevant professional-educational literature, there is evidence that the cultivation and development of HOCS capabilities, including students’ PS abilities, can be achieved through the following strategies and methods: teaching-learning combining case studies; question asking capabilities; and teaching-learning combining mini projects (Overton and Randles 2015; Savery and Duffy 1995).

In the control group, conventional instruction methods were used. The methods were teacher-centered, and the students mostly acted as a passive audience. Most of the lessons were conducted in the form of a lecture in which the teacher stood in front of the class and presented the material with the help of a board and marker, combining a few questions, answers, and discussion segments. Sometimes the teachers used a presentation and video. At the end of the lesson, the teachers usually handed out 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 the transfer of information.

**Research Procedure**

The pre- and post-PBL-HOCS research questionnaires were self-developed (see appendix 1). They were given to both the experimental and the control groups. Prior to their delivery, the questionnaires were validated by four experts who examined their suitability in terms of their structure and the validity of the content. The results indicated a high percentage of consensus among the experts – 90.5% and 85.4%, respectively. Each questionnaire consisted of eight open-ended HOCS-oriented questions/issues to which the students were asked to respond. For the pre and post questionnaires, the reliability of the acceptable internal traceability ($∝\_{cronbah})$ was 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 three evaluators to determine the Inter-Rating 0, 1, 2 as follows:

* No response or an 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 response. The LOCS range is characterized by algorithmic knowledge-level questions, whose responses or solutions require only a primarily recall, or the application of a theory and/or knowledge that the student possesses within known situations and contexts. On the other hand, an HOCS-level response extends beyond one "correct", unequivocal or one-dimensional response, and is sometimes based on other HOCS capabilities such as system thinking, critical thinking, evaluative thinking, creative thinking, PB, 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 or knowledge that are unfamiliar to the student- responder. Students’ response(s) on an HOCS level scored two, meaning that the PS capabilities of the responding student was within this level.

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

**Selected Students' Responses (For the Same Item):**

The item (from the 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 residents of the city, 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 consulted with you, what would you suggest that he do to solve the factory's sewage problem(s)? Explain your response."

* Response score 0:

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

This response was assessed as irrelevant because it is does not address the problem presented: the student makes no suggestion to the mayor as to how to solve the problem created by the factory.

* Response score 1 (LOCS):

- Student’s 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’s 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 as 2 (HOCS level) since here the student is dealing with contradictions within a complex, non-algorithmic and multi-component system.

**Agreement Among Evaluators**

To verify the evaluations of the three evaluators, the degree of agreement between evaluator 1 and evaluators 2 and 3 was examined in both the pre and post questionnaires. This was achieved by comparing the number of responses (out of eight) which were 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. 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 evaluations of evaluator 1 and 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 an agreement between the evaluations of evaluator 1 and evaluators 2 and 3 for the number of responses (out of eight) that were scored as HOCS responses to both the pre and post questionnaires.

**Students' "Distribution" on the LOCS / HOCS Levels**

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

• Students who responded to zero to two questionnaire items (out of the total eight) on the HOCS level were rated as "LOCS students";

• Students who responded to three to five questionnaire items, on the HOCS level, were rated as "mixed LOCS-HOCS students";

• Students who responded to six to eight questionnaire items, on the HOCS level, were rated as "HOCS students".

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

**Results**

**Table 2.** **The pre-post percentage distribution of the students' responses on HOCS levels 0, 1 and 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 the experimental and the control groups. However, despite the positive increase in score 2, which reflects responses at the HOCS level, these initial values show a low achievement at the HOCS level. Table 3 presents the percentage frequency of “the number of responses out of 8” that were scored as responses at the HOCS level in both the pre and post questionnaires 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 neither the experimental nor the control group provided HOCS-level responses to all the eight items in the pre and post questionnaires. The number of responses at the maximum HOCS level for students in both groups was only six. Upon further examination, the distribution of the students' responses on the HOCS level indicates a greater advantage for the experimental group. Using the data in the table above, the estimated proportion of students classified according to one of the three students’ "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" |  |

In the pre questionnaire, the "LOCS students" levels in the experimental and control groups are 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 those of the control group (0.138). However, there is also no significant difference between 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 is no significant difference between the experimental and the control group in the "mixed LOCS-HOCS students" level and the "LOCS students" level: 0.760 and 0.834, respectively. The "mixed LOCS-HOCS" level in the experimental group is 0.163, while the level in the control group is essentially the same, 0.138. The proportion of the "HOCS students" level in the experimental group is 0.077, and 0.028 in the control group. Interestingly, this "LOCS students" level is the highest in each of the two study groups. In the transition from the pre to post stages, an insignificant improvement was observed in the "HOCS student" level of the experimental group, with an increase of 0.048. In contrast, the same level in the control group increased by 0.01.

The research question was examined through the application of the Generalized Estimation Equation (GEE) test, while comparing the distribution of the students’ HOCS level in the pre and post questionnaires. The variables used in the GEE application were: the dependent variable (the "HOCS students" level); the intra-test variable (stage of the research); and the independent variable (the teaching-learning-assessment method). This question was examined in two stages: in the first, the GEE was used to reveal if there is a gap between the pre and post stages in PS. 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 a 95% confidence level for OR).

**Table 5.** **GEE test to examine the relationship between the 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 research stage (pre relative to post) |

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

The pre-post odds ratio relating to the students’ "HOCS level for problem solving" (OR=0.71) was significant at the 0.05 significance level. The result indicates 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 concluded that the chance of obtaining results at the higher level (HOCS vs. LOCS and/or LOCS-HOCS, HOCS and/or LOCS-HOCS vs. LOCS) is greater in the post stage than in the pre stage. Table 6 presents the changes in the proportions of each level in the transition from the pre to post stages.

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

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

After a difference had been identified in the PS capabilities at the pre and post stages, the GEE test was applied (again) to check whether the teaching, learning and assessment method is the source of this difference. The following table summarizes the results:

**Table 7. The relationship between the research stage and PS capabilities**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | $$95\%CI for OR$$ | $$OR$$ | $$b$$ |  | 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 research stage (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 research stage (pre relative to post) |  |

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

In 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 concluded that, in the experimental group, the chance of obtaining results at higher levels (HOCS vs. LOCS and/or LOCS-HOCS; HOCS and/or LOCS-HOCS vs. LOCS) is higher in the post stage than in the pre stage. Table 3 shows that, although the LOCS level remained the highest in the post stage (0.76), the students’ LOCS level for this group decreased in the post stage by 0.086 (compared to the proportion in the pre stage). This was in contrast to an increase in the LOCS-HOCS and HOCS levels (in the post compared to the pre stages) 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 stages of the "HOCS students" level in PS, which is very close to 1 (OR = 0.926). The result signifies that for this group, the chances of obtaining results at higher levels (HOCS vs. LOCS and/or LOCS-HOCS, HOCS and/or LOCS-HOCS vs. LOCS) in the post and pre stages are the same.

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

The most important research-based result of this study is that the initial PS capabilities (post-pre) improved over time in both the experimental and the control groups, and 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 capabilities. 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 students exposed to PBL significantly improved their PS and HOCS skills. These findings offer empirical evidence of the effectiveness of PBL in science learning among students. In a related study, Ferreira and Trudel (2012) reported that, thanks to PBL, students benefitted from: (1) greater peer interaction; (2) a greater sense of control over their studies. On the other hand, traditional-algorithmic-based teaching (the 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). However, traditional teaching primarily involves memorizing knowledge (Barak, Ben-Chaim and Zoller 2007; Ivic, 2016). Therefore, students’ skills, critical thinking, PS and preparation for lifelong learning cannot be developed. Ivic (2016) questioned "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". Based on its conclusions, the present study could make similar claims.

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

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

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**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 that there is a severe shortage of organ donations.
5. Suggest possible way(s) to solve the shortage problem.
6. Propose a possible solution, devised by you, to raise public awareness about the purpose and 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 you think that the problem you presented is meaningful.

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