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Abstract

Despite the recognized efficacy of project-based learning (PBL) in fostering students' conceptual understanding, there is a notable gap in comprehensive research on its cross-disciplinary aspects, especially within the Lebanese context. This study seeks to investigate the impact of the Cross-Disciplinary Project-Based Learning Approach (CDPBLA) on the development of higher order thinking skills (HOTS) among Lebanese secondary school students through the implementation of everyday life research projects. The central research question probes whether the utilization of cross-disciplinary project-based learning approach could contribute to improvements in students' HOTS. By exploring the effectiveness of CDPBLA in the Lebanese educational context, this research aims to provide valuable insights into the potential of cross-disciplinary project-based learning to enhance HOTS skills acquisition and practice among secondary students. The results show promising outcomes where cross-disciplinary project has helped students in fostering many of their HOTS skills.

Introduction

Promoting higher-order thinking skills (HOTS) is essential for equipping students with the competencies required to deal with the challenges of the 21st century. Those skills include a broad range of capabilities such as critical thinking, problem-solving, analysis, and creativity, all of which are vital for both academic and professional success. In science education, fostering HOTS enables students to construct new knowledge, integrate information, and transfer skills across various contexts (Getha-Eby et al., 2014; Maxwell et al., 2015; Miterianifa et al., 2020; Partnership for 21st Century Skills, 2017; Pedaste et al., 2015; Sukontawaree et al., 2022). Recent research has highlighted the significant impact of Cross-Disciplinary Project-Based Learning Approach (CDPBLA)**,** a form of inquiry-based learning (IBL), in promoting HOTS. Studies have shown that CDPBLA fosters critical thinking, collaboration, and creativity, which are essential for success in modern educational and professional environments (Belland et al., 2019; Chu et al., 2021; Kuo et al., 2019). Additionally, CDPBLA has been found to improve students' ability to apply knowledge across disciplines, promoting deeper engagement and sustained learning (Kapur & Bielaczyc, 2020; Lazonder & Harmsen, 2020). The literature includes several CDPBLA frameworks, where all involves the concepts of crossdisciplinarity with the relevant teaching learning approach and assessment.

Cross-Disciplinary Project-Based Learning Approach (CDPBLA) Framework

Crossdisciplinarity Integration

CDPBLA integrates ideas, approaches, and viewpoints from two or more disciplines. This method fosters a comprehensive grasp of real-world challenges by encouraging students to identify links across courses like science, technology, engineering, mathematics (STEM), and the social sciences (Krajcik, 2015; Kuo et al., 2019).

Project-Based Learning (PBL)

An interdisciplinary and inquiry-based learning approach dating back to 1897, has been widely adopted in modern education. However, despite its long history, comprehensive research on its effectiveness remains limited (Behizadeh, 2014; Burns & Lewis, 2016; Hill, 2014; Krajcik, 2015; Strobel & van Barneveld, 2009). Recent studies have begun to address this gap, demonstrating that PBL enhances students' critical thinking, collaboration, and problem-solving skills, which are essential for 21st-century learning (Belland et al., 2019; Chu et al., 2021; Kuo et al., 2019).

Support and Scaffolding

Structured support and scaffolding are essential for assisting students in navigating the challenges of cross-disciplinary project-based learning and assessment (CDPBLA). In order to assist students, overcome obstacles and cultivate higher-order thinking abilities, scaffolding entails giving them the right materials, prompt feedback, and supervised instruction (Belland et al., 2019; Kapur & Bielaczyc, 2020). Scaffolding in the context of CDPBLA can take several forms including cognitive, metacognitive, social and technological support.

Evaluation and Reflection

In CDPBLA, evaluation emphasizes both the procedure and the final result. Summative evaluations analyze the final results, whereas formative assessments—like peer reviews and self-assessments—are used to track progress. A crucial element is reflection, which pushes students to consider their educational experiences critically and pinpoint areas in which they can grow (Sahin & Top, 2018; Lazonder & Harmsen, 2020).

21st-Century Skills

CDPBLA is designed to develop essential 21st-century skills (Partnership for 21st Century Skills, 2017), including:

- Critical Thinking: Analyzing information and making evidence-based decisions.
- Creativity: Generating innovative solutions to complex problems.
- Collaboration: Working effectively in diverse teams.
- Communication: Articulating ideas clearly and persuasively.

PBL has also been demonstrated to enhance students' capacity to apply knowledge across many academic fields, which promotes longer-term retention and deeper engagement (Kapur & Bielaczyc, 2020; Lazonder & Harmsen, 2020). In addition, PBL has been very successful in fostering scientific literacy and attitudes and equipping students to face real-world problems (Hanif et al., 2019; Sahin & Top, 2018; Kolmos & de Graaff, 2021). These results show PBL's transformative potential as a pedagogical approach, but they also point to the need for more study to completely comprehend its effects in a variety of educational contexts. Although PBL has the potential to improve learning, its complexity makes it difficult to completely execute in order to reach the intended learning objectives (Goldstein, 2016). Further research is necessary to fully comprehend the elements of cross-disciplinary PBL and how it affects students' learning, especially in environments that have received little attention, such Lebanese high schools (Peng, Wang, & Sampson, 2017).

Higher-Order Thinking Skills (HOTS)

By large, HOTS refer to cognitive processes that surpass simple information recall or comprehension. These skills allow students to apply knowledge in challenging and new contexts and include critical thinking, problem-solving, analysis, synthesis, assessment, and creativity (Brookhart, 2010; Anderson & Krathwohl, 2001). According to Zohar and Dori (2003), HOTS are crucial for developing scientific literacy in science education because they allow students to participate in inquiry, experimentation, and evidence-based reasoning.

Framework for HOTS in Science Education

Contemporary education literature reveals several HOTS frameworks, that highlight various cognitive.
The Revised Bloom Taxonomy version (Anderson and Krathwohl, 2001) offers a popular framework for HOTS. It includes six cognitive levels to classify students' cognitive processes, as follow:

- Remembering: Recalling fundamental ideas and facts.
- Understanding: Providing an explanation of concepts or ideas.
- Applying: Using knowledge in new situations.
- Analyzing: Breaking information into parts to explore relationships.
- Evaluating: Justifying decisions or opinions based on evidence.

In science education, the upper three levels (analyzing, evaluating, and creating) are particularly emphasized as they align with scientific inquiry and problem-solving (Zohar & Dori, 2003). In addition, the 21st-century learning frameworks, which emphasize the value of teamwork, communication, and metacognition in preparing students for a world that is becoming more linked and dynamic, further assist the development of HOTS (Partnership for 21st Century Skills, 2017). Metacognitive skills, such as planning, monitoring, and reflecting on one's thinking, are critical for developing HOTS. These skills enable students to regulate their learning processes and adapt strategies when solving scientific problems (Zohar & Barzilai, 2013). Moreover, Scientific inquiry framework, which include developing questions, planning experiments, evaluating data, and drawing conclusions, is closely related to HOTS in science education (Pedaste et al., 2015). A crucial element of HOTS is problem-solving, which calls on students to use their scientific knowledge to tackle challenging, open-ended issues (Miterianifa et al., 2020).

Given that this study is within the science education context, Scientific Inquiry framework will be adopted, namely the problem-solving skills PS that are as mentioned above a crucial element of HOTS. In fact, frameworks that emphasize the value HOTS in science education, such as Bloom's Revised Taxonomy and the Next Generation Science Standards (NGSS), emphasize these problem-solving skills, which are essential to scientific inquiry (Anderson & Krathwohl, 2001; National Research Council, 2012).

Acquiring PS skills help students to successfully navigate difficult scientific problems and gain a deeper comprehension of scientific principles. According to Anderson and Krathwohl (2001) and Pedaste et al. (2015), these skills entail a number of cognitive processes, such as identifying the problem (recognizing and defining the issue to be addressed), selecting relevant information (collecting and prioritizing data pertinent to the problem), and identifying variables (figuring out the factors that influence the problem). Once the problem is understood, students formulate hypotheses (proposing testable explanations) and make predictions (anticipating outcomes based on hypotheses) (Zohar & Dori, 2003; Chinn & Malhotra, 2002). The use of mathematical representation (applying mathematical models to analyze data) and processing information accurately (ensuring data is correctly interpreted and organized) are critical for analyzing and solving problems (Kapur & Bielaczyc, 2020; National Research Council, 2012). Last but not least, students use reasoning to derive conclusions and improve hypotheses and evaluate data to find patterns or trends (Pedaste et al., 2015; Krajcik & Shin, 2014).
The figure below shows the various PS skills addressed in the study.

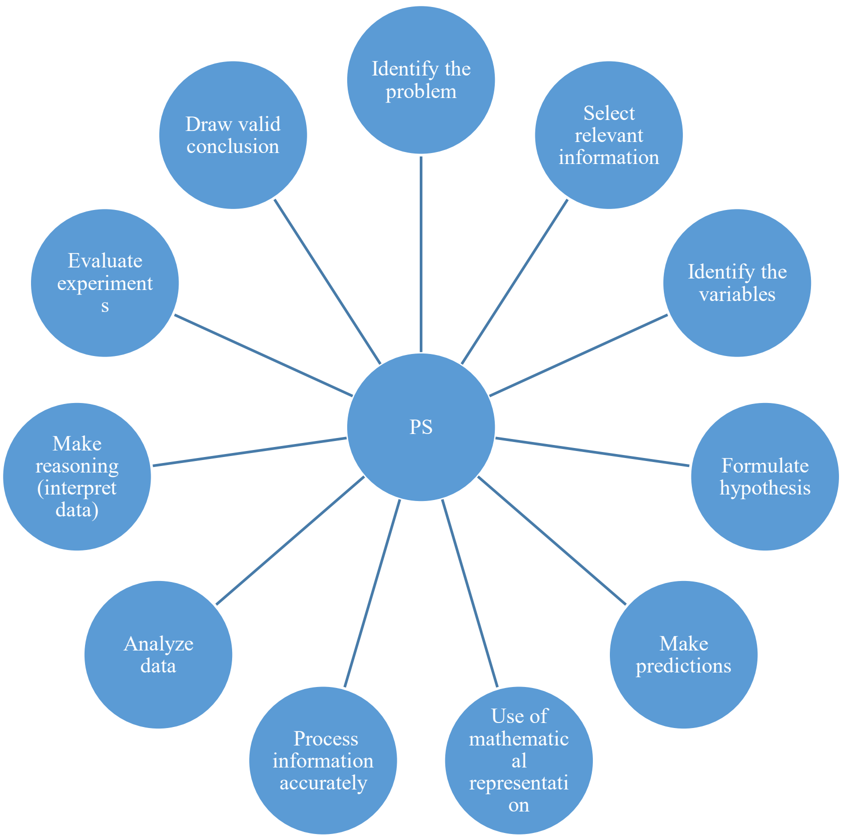

Figure 1. Problem-Solving Skills

Cross-Disciplinary Project-Based Learning Approach and Problem-Solving Skills

Mayer (2014) asserts that problem-solving is the process of coming up with a way to accomplish an objective that has never been done before—in other words, determining how to change a given state into an objective state. Students must also acquire and comprehend a variety of scientific ideas and apply them methodically to real-world problems in order to develop PS skills. They include scientific reasoning skills like detecting a problem and asking relevant questions, collecting and analyzing data, drawing conclusions, synthesizing and evaluating data from various sources (National Research Council, 2012; OECD, 2019; Pellegrino & Hilton, 2012; Partnership for 21st Century Learning [P21], 2019).

Therefore, engaging students in CDPBLA where they had to investigate a complex real-life problem is assumed to foster their PS skills which in turns would lead to enhance the development of HOTS. According to recent research, developing HOTS including critical analysis, creative problem-solving, and systems thinking requires cross-disciplinary learning, which integrates concepts and techniques from several disciplines. Teachers can develop deeper cognitive skills that go across traditional academic boundaries by involving students in cross-disciplinary problem-based learning (PBL) (OECD, 2019; WEF, 2023).

Purpose of the Study

This research aims to examine the effect of CDPBLA on students' HOTS, by implementing research projects from everyday life in a Lebanese secondary high school. The study seeks answers for the following research question:

Would the use of CDPBLA improve students' HOTS, namely the skills of problem solving?

It is assumed that the CDPBLA would enhance the acquisition and application of problem-solving skills, consequently enhance the development of students' HOTS.

Method

The research utilized a quasi-experimental "one-group pretest-posttest" design, employing a mixed methods approach to assess the impact of CDPBLA on students' PS skills. The study included 4 phases over 20 weeks with six integrated disciplines in the study, Biology, chemistry, Physics, English and Arabic, where all the learning outcomes were part of curriculum.

Mixed-Methods Approach

A mixed-methods paradigm combined quantitative and qualitative methods, offering flexibility in their prioritization. Integration occurred at various stages, enhancing a holistic understanding of the phenomenon under study through triangulation. The study employed a concurrent triangulation strategy, integrating data during both analysis and interpretation phases (Johnson & Onwuegbuzie, 2004; Terrell, 2011).

Sample

The sample consists of 62 grade ten students, aged between 14 and 16, in a Lebanese public high school in Mount-Lebanon. They are Arabic native speakers and English is the language of instruction in Biology, Chemistry and Physics. The study was conducted in the second semester of the school year, noting that the researchers had explicitly used inquiry across the scientific subjects in the first semester, expecting students to have acquired basic procedural knowledge, scientific reasoning skills, and conceptual knowledge. Despite these assumptions, 10th graders were considered novices in conducting scientific investigations, making them suitable for the study. Moreover, 10th grade presented a practical advantage, offering a sizable cohort necessary for forming collaborative groups. 12 collaborative teams of five or six members each were formed. These groups were assigned with the task of designing and conducting cross-disciplinary projects.

Procedure

As mentioned above, the study included four phases. The first phase of the study, first four weeks, both teachers and students were introduced to the inquiry process of cross-disciplinary PBL. Students were asked to choose a problem from their daily life and they chose to investigate the quality of drinking water get from various resources in Mount-Lebanon. Samples of drinking water identified by students themselves were collected and tested by experts. The microbiological results of tested water and scaffolding tools were provided to students. The second phase was the first administration of the PS test (pretest). The following fourteen weeks, phase three, consisted of the period of implementing the study, where students worked in collaborative groups to perform their cross-disciplinary research project under the supervision and guidance of the teachers. Many activities were involved such as field trips to water natural resources in the area and interviews with the municipality. The third phase was in week 19, where the students presented their artifacts (Brochure and article about the quality of drinking water submitted in the school journal) to the school and societal community where they practiced reflection about their projects. In the last week, phase four, the PS test was administrated as post-test.

Ethical Considerations

Firstly, the researchers sought permission from the school administration to conduct the study. Then, the researchers communicated the teachers involved in the study, the students and their parents about the research purpose and procedure to obtain their consent. They were informed about the confidentiality of data and their voluntary participation in the study.

Data Collection and Analysis

The data was collected by performing a Problem Solving (PS) test constructed by the researchers. Following the educational literature suggestions and criteria for assessing the PS skills, the test's questions constructed for the PS test were all of the authentic open-ended type where they included "real life" problematic situations that simulated the problems faced by a scientist or expert in a particular field (Pedaste et al., 2015; Runnel, Pedaste,

& Leijen, 2013; Lai, 2011; Ku, 2009; Halpern, 1998; Wiggins, 1989). The test was piloted and validated by three external examiners.

Pre-Post PS Test

The test included nine open-ended questions (26 sub questions). Three sub questions distributed among different questions (except for the prediction skill which was tested twice) were intended to assess one of the 11 PS categories of skills. Each question in the test included a stem made up either of relevant text information, figures, and/or documents retrieved from high school biology books, bio-guides used in Lebanon and international biology tests; then the sub questions were constructed by the researcher in a way that is most consistent with the given specific problematic situation and the PS skill being assessed. The criteria for mastering each of the tested skill retrieved from science literature and their numerical scores are represented in table 1.

Table 1. Problem Solving Skills, Their Assessment Criteria, Corresponding Questions and Sub Questions, and Total Scores

Problem solving skills	Criteria used to assess PS skills	Questions and sub-questions	Total scores
1- Identify the problem / pose questions (PSQ)	-Write testable question (s) for a problem that includes relation(s) between variables	V (1), VI (2), IX (3)	3
2- Select relevant information (SRI)	-Select relevant statements from a text, select relevant numbers or values from charts, diagrams, table and so on	I (1), III (1), IV (4)	3
3- Identify the variables (IV)	-Identify different types of variables (changed, measured, & constant variables) present in the given information.	IV (3), V (4), IX (2)	5
4- Formulate hypothesis (FH)	-Formulate/suppose relations between variables	II (2), V (2), IX (4)	3
5- Make predictions (PRE)	-Write a statement about what the student believes will happen when the hypothesis is put to the test.	VI (1), VII (3)	2
6- Use of mathematical representation (UMR)	-Present information appropriately in a variety of forms, including written summaries, extended writing, tables and/or graphs (line graphs, bar graphs, pie charts and /or diagrams).	III (2), VII (2), IX (1)	9
7- Process information	-Process information accurately using calculations including percentages, averages and/or ratios. -	I (2), I (3), VII (1)	3

Problem solving skills	Criteria used to assess PS skills	Questions and sub-questions	Total scores
accurately (PIA)	Significant figures and units should be used appropriately		
8- Analyze data (ANA)	-Identify the trends or connections between the variables of the given data	II (1), IV (5), VIII (1)	5.75
9-Make reasoning (interpret data) (REA)	-Make meaning out of collected data and synthesize new knowledge.	II (1), IV (5), VIII (1)	1.75
10-Evaluate experiments (EVA)	-Evaluate experimental procedures by commenting on its components (such as the purpose and limitations of equipment	IV (1), IV (2), V (3)	3
11- Draw valid conclusion (CON)	-Relate generally between the evidences and the claim and give explanation supported by evidence; & -validate or not the tested hypotheses.	II (1), IV (5), VIII (1)	1.5

As shown in table 1, a numerical scoring scale was used to reflect the students' mastery of a PS skill. The score is related to the time and effort needed to accomplish the task. A skill's (category's) score is merely the average of the student's scores on every sub question intended to evaluate that category. The overall score is the average of students' individual scores on all of the test's sub questions. The maximum score of the whole test is 40 marks. Moreover, in order to harvest any signs of change in the quality of students' PS skills after implementing the investigation, the students' answers on sub questions were numerically scored and categorized based on the level of their compatibility (correctness, clarity and relevance) with the criteria of performance in problem solving skills adopted in relevant literature. Three levels were identified in relation to varied score ranges. Higher scores on sub questions are associated with higher levels of skill mastering. It is worth noting that the quality of the students' answers was determined by comparing them with suggested complete answers set by the researcher for each sub question based on criteria. In general, the students' answers were categorized into three categories: complete (CA), incomplete (IA), and wrong or no answers (N, WA). These were used to reflect the students' levels of skill mastering. Table 2 represents the Problem-solving skills' score ranges and the students' answers level of compatibility with criteria:

Table 1. Problem Solving Skill's Score Ranges and The Student Answers' Level of Compatibility with Criteria

Problem solving categories	Levels of the students' answers			Mean scores
	No or Wrong answer N, WA	Incomplete answer IA	Complete answer CA	
1-Identify the problem/pose questions (PSQ)	0	0.25-2.5	2.75- 3	1.5
2-Select relevant information (SRI)	0	0.25-2.5	2.75-3	1.5

Problem solving categories	Levels of the students' answers			Mean scores
	No or Wrong answer N, WA	Incomplete answer IA	Complete answer CA	
3-Identify the variables (IV)	0	0.25-4.5	4.75-5	2.5
4-Formulate hypotheses (FH)	0	0.25-2.5	2.75-3	1.5
5-Make predictions (PRE)	0	0.25-1.5	1.75-2	1
6-Use of mathematical representations (UMR)	0	0.25-7.5	7.75-9	4.5
7-Process information accurately (PIA)	0	0.25-2.5	2.75-3	1.5
8-Analyze data (ANA)	0	0.25-5	5.25-5.75	2.9
9-Make reasoning (interpret data) (REA)	0	0.25-1.25	1.5-1.75	0.9
10-Evaluate experiments (EVA)	0	0.25-2.5	2.75-3	1.5
11-Draw valid conclusions (CON)	0	0.25-1	1.25-1.5	0.7
Total PS test		40		20

Data processing of the pre-post PS tests was principally based on the following factors: the PS pre-posttests comparison, results of the paired sample T-test, in addition to quantitative and qualitative changes in the students' PS skills. To further investigate students' development of PS skills, three participants chosen randomly for each skill, their individual pre-post answers were compared searching for changes in the quality of their skill. Moreover, aiming at eliciting signs on students' acquirement or development of PS skills, the overall percentages of students who had provided complete and incomplete answers on set of PS sub-questions targeted a specific skill in both pre and posttests were summated. Results obtained were then used as quantitative and qualitative signs on changes in students' PS skills due probably to implementing cross-disciplinary research project. Those changes (if any) were considered as indicators on the presence of favorable/or unfavorable signs of acquiring or developing PS skills by the study's participants. The variations in those signs were then used to evaluate the effect of CDPBLA on students' problem-solving skills based on the first and second analytical steps represented in Table 3.

Table 3. First and Second Analytical Steps Used for The Assessment of The CDPBLA's Effect on Students' PS Skills

Evaluation of the CDPBLA's effect on students' PS skills	Signs' description	Specific indicators
Strongly promising effect SPE	Favorable significant signs (FSS) of acquirement of and/or improvement in a specific PS skill	a) significant increase in the mean scores from pre to posttest concerning a a specific PS skill b) increase in the overall percentage of students who got marks above the standard mean for a specific PS skill in the posttest compared to the pretest

Evaluation of the CDPBLA’s effect on students’ PS skills	Signs’description	Specific indicators
		c) improvement in the quality of a specific PS skill elicited from the comparison between the students' pre-post answers d) increase in the summated overall percentages of students who had provided incomplete and complete answers to PS sub-questions which targeted a specific PS skill in the posttest compared to the pretest
Promising effect PE	Favorable but non-significant signs (FNS) of acquirement of and/or improvement in a specific PS skill	a) non-significant increase in the mean scores from pre to posttest concerning a a specific PS skill b) increase in the overall percentage of students who got marks above the standard mean for a specific PS skill in the posttest compared to the pretest c) improvement in the quality of a specific PS skill elicited from the comparison between the students' pre-post answers d) increase in the summated overall percentages of students who had provided incomplete and complete answers to PS sub-questions which targeted a specific PS skill in the posttest compared to the pretest
No effect NE	Unfavorable signs (UFS) (the specific PS skill was not aquired or improved)	a) drop or constancy in the mean scores from pre to posttest concerning a specific PS skill b) constancy or drop in the overall percentage of students who got marks above the standard mean for a specific PS skill in the posttest compared to the pretest c) no improvement in the quality of a specific PS skill elicited from the comparison between the students' pre-post answers d) constancy or drop in the summated overall percentages of students who had provided incomplete and complete answers to PS sub-questions which targeted a specific PS skill in the posttest compared to the pretest

Results

Data processing of the pre-post PS tests was principally based on the following factors: the PS pre-posttests comparison, results of the paired sample T-test, and quantitative and qualitative changes in the students’ PS skills.

The comparison between the overall percentage of students who got marks above the standard mean for a specific problem-solving skill in the pre and posttests shows improvements in students' eight out of 11 PS skills (PSQ, SRI, IV, UMR, ANA, REA, EVA, and CON).The results obtained from the paired sample T-test indicate that implementing the cross-disciplinary project-based learning approach CDPBLA had significantly improved only three out of the measured 11 PS skills (PSQ, EVA, and ANA skills) which in its turn significantly improved their total PS skills.

The changes in the students' problem-solving skills were elicited from: a) the comparison between the summated overall percentages of students' who had provided both incomplete and complete answers in both pre and posttests; and b) the deep analysis of the quality of the students' individual pre-post answers. The increase in the summated overall percentages of students who had provided both incomplete and complete answers in the posttest compared to that in the pretest regarding a specific measured PS skills was considered as a quantitative and qualitative indicator on the presence of favorable signs of students' improvement in that skill; and shifts in the level of those students' skills from being undeveloped before conducting their research project to becoming slightly developed or well-developed after conducting it. The outcomes of the first analytical step used for the assessment of CDPBLA's effect on students' PS skills elicited from the pre and post PS tests are represented in Table 4.

Table 2. The Outcomes of The First Analytical Step Used for The Assessment of CDPBLA's Effect on Students' PS Skills Elicited from The Pre and Post PS Tests

Types of specific PS skills measured by pre-post PS tests	Type and level of the change in the mean scores from pre to posttest (results of the paired samples T-test)	Total overall % of students who get marks above the standard mean		The sum of the overall % of students' who had provided incomplete and complete answers in pre-post PS tests IA + CA		Signs of CDPBLA's effect
		Pre	Post	Pre	Post	
1-Identify the problem by posing scientific questions (PSQ)	Significant increase	19.4	45.2	23.7	44.6	FSS
2-Select relevant information (SRI)	Non-significant increase	68	85	71.5	76.3	FNS
3-Identify the variables (IV)	Non-significant increase	13	27	27.4	36.6	FNS
4-Formulate hypothesis (FH)	Non-significant increase	3.22	3.22	8.7	9.6	UFS
5-Make predictions	Non-significant decrease	74.2	71	71.7	69.4	UFS

Types of specific PS skills measured by pre-post PS tests	Type and level of the change in the mean scores from pre to posttest (results of the paired samples T-test)	Total overall % of students who get marks above the standard mean		The sum of the overall % of students' who had provided incomplete and complete answers in pre-post PS tests IA + CA		Signs of CDPBLA's effect
		Pre	Post	Pre	Post	
(PRE)						
6-Use of mathematical representation (UMR)	Non-significant increase	68	74	75.2	85	FNS
7-Process information accurately (PIA)	Non-significant decrease	46.8	46.8	53.24	51.65	UFS
8-Analyze data (ANA)	Significant increase	48	60	61.3	65.6	FSS
9-Make reasoning (interpret data) (REA)	Non-significant increase	12.9	24.19	22.1	18.9	UFS
10-Evaluate experiments (EVA)	Significant increase	12.9	24.2	31.7	43	FSS
11-Draw valid conclusion (CON)	Non-significant increase	12.9	17.74	28	37.6	FNS

The findings of the first analytical step show A) Favorable significant signs (FSS) of students' acquirement or development of the PSQ, ANA, and EVA skills due to the increases observed in the overall percentages of students' who get marks above the standard mean and who had provided CA and IA to items which targeted those skills in the posttest compared to the pretest; in addition to the increase in the mean scores which were shown to be significant by the paired samples T-test (Table 4 above) for all of these three skills. B) Favorable but non-significant signs (FNS) of students' acquirement or development of the SRI, IV, UMR, and CON skills due to the increases observed in the overall percentages of students' who get marks above the standard mean and who had provided CA and IA in the posttest compared to the pretest; in addition to the increase in the mean scores which were shown to be non-significant by the paired samples T-test for all of these three skills. C) Unfavorable signs (UFS) of students' acquirement or development of the FH, PRE, PIA, and REA skills due to the decrease/ and or constancy observed in at least one of the four quantitative or qualitative indicators used to elicit favorable signs of acquiring or developing a specific PS skill.

Results of table 4 above show (1) a constancy in the overall percentages of students who had get marks above the standard mean in the posttest compared to that in the pretest was detected for both FH and PIA skills (46.8% for PIA and 3.22% for FH in both pre and posttests) ; (2) decrease in percentages for the PRE skill (in posttest 71% < 74.2% in pretest); (3) non-significant decreases in mean scores from pre to posttest for PRE and PIA skills; (4) decreases from pre to posttest in the summated overall percentages of students who had provided IA and CA to items which targeted PRE (71.7% in post < 69.4% in pre), PIA (53.24% in post < 51.65% in pre), and REA (22.1% in post < 18.9% in pre) skills.

Moreover, the deep qualitative analysis of the students' pre-post answers revealed the following: a) absence (or very few) of signs of improvement in the level of FH, PIA, REA & PRE skills (four out of 11 PS skills); b) presence of favorable signs of improvement in the level of PSQ, ANA, EVA, IV, SRI, UMR, & CON skills (seven out of 11 PS skills). The effect of the CDPBLA on students' PS skills was evaluated based on PS tests' results and on the first and second analytical steps (Table 4). Table 5 represents the outcomes of these steps.

Table 3. The Outcomes of the First and Second Analytical Steps used for the Assessment of the CDPBLA's Effect on Students' PS Skills Obtained from Results of Pre-Post PS Tests

PS Skills	PSQ	SRI	IV	FH	PRE	UMR	PIA	ANA	REA	EVA	CON
CDPBLA's effect on students' PS skills	SPE	PE	PE	NE	NE	PE	NE	SPE	NE	SPE	PE

Consequently, in line with the results and the analytical steps, the effect of CDPBLA was explained as follows: it was strongly promising (SPE) on students' PSQ, ANA, and EVA skills, promising (PE) on students' IV, SRI, UMR, and CON skills and absent (NE) on students' FH, PRE, PIA, and REA skills.

Discussion

Referring to the study findings concerning the 11 students' PS skills it might be reasonably argued that the effect of CDPBLA was strongly promising the "Identify the problem by posing scientific questions (PSQ)", "Evaluate experiments (EVA)", and "Analyze data (ANA)" skills. In addition, CDPBLA seemed to have a promising effect on students' "Select relevant information (SRI)", "Identify the variables (IV)", "Use of mathematical representation (UMR)", and "Draw valid conclusion (CON)" skills. However, CDPBLA had no effect on students' "Formulate hypothesis (FH)", "Make predictions (PRE)", "Process information accurately (PIA)", and "Make reasoning/interpret data (REA) skills.

The results of the study are consistent with previous research, which supports the use of creative active learning strategies like CDPBLA (Belland et al., 2022; Chen & Yang, 2019; Kokotsaki et al., 2022). This method is especially beneficial since it requires students to integrate various viewpoints and work together with peers and external stakeholders while immersing them in the investigation of real-world, authentic problems that cut across disciplinary boundaries (Guo et al., 2020; Kolmos & de Graaff, 2021; Miller et al., 2021). CDPBLA educational strength is its capacity to foster HOTS while promoting deeper learning via problem-solving in complex, multidisciplinary situations (Capraro et al., 2022; Krajcik & Shin, 2022; Larmer, 2022; OECD, 2019; WEF, 2023).

Accordingly, a number of researchers have empirically verified that incorporating CDPBLA into science instruction helps students develop: a) science-specific skills like investigative, process, and problem-solving abilities (Barak & Shachar, 2008; Hong et al., 2012; Walker & Warfa, 2017); b) non-science-specific skills like critical thinking, metacognition, autonomy, and responsibility (Bell, 2010; Burns & Lewis, 2016; Chin & Chia, 2004; Fallik et al., 2008; Sadeh & Zion, 2012); c) leadership and creative abilities (Alfonso, 2017; Barak & Shachar, 2008; Habok & Nagy, 2016; Tural et al., 2009); and d) interpersonal competencies and collaborative abilities (Emery & Morgan, 2017; Fallik et al., 2008; Rozenszayn & Assaraf, 2011). Developing those fundamental 21st-century skills is necessary for students' success in life and future careers (Chu et al., 2017; Craft & Capraro, 2017; Drake et al., 2015; Smyth, 2017).

Despite that, engaging students in a single project-based learning approach appeared insufficient for improving significantly all of the students' PS skills. It was evidently proven by some educational researchers that students must be repeatedly engaged in such approaches where they need to be provided with an opportunity to practice HOTS. According to Hackling and Garnett (1995), Hasni et al. (2016), Krajcik & Blumenfeld (2006), Peng et al. (2017), Walker & Warfa (2017), and others, in order to achieve meaningful learning outcomes, HOTS should be: (1) aligned with authentic scientific practices; (2) integrated with content instruction; and (3) developed over an extended period of time (several years). These ideas are supported by recent research, which highlights the importance of rigorous, inquiry-based learning and clear critical thinking scaffolding in developing students' deep conceptual understanding and problem-solving skills (Bathgate et al., 2019; Lazonder & Harmsen, 2020; Osborne et al., 2022; Schwichow et al., 2022).

Conclusion

The main purpose of the study is to investigate the effect of CDPBLA on the development of students HOTS, which was operationally defined and measured as PS eleven skills. The findings show that among the eleven measured PS skills, favorable signs of skill development were detected in seven of them. Based on that, it may be assumed that conducting a cross-disciplinary project has helped students in improving many of their PS's skills and consequently we may deduce that CDPBLA has enhanced the participants' HOTS development. The study was conducted over a relatively short period, involving one cross-disciplinary project with a small sample in one school. As mentioned above the results were promising and it is recommended investigate further the effect of CDPBLA on the acquisition and practice of HOTS with a larger sample over a longer period of time involving several projects to get more reliable and valid results.

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