Influence of Problem-Based Learning on Conceptual Understanding and Critical Thinking regarding Quantum Physics

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Abstract

The aim of this research is to investigate effects of Problem Based Learning (PBL) method on Conceptual Understanding (CU) and Critical Thinking Skills (CTS) specifically concerning Black Body Radiation, Photoelectric Effect and Compton Scattering. Throughout the study, pretest–posttest control grouped semi-experimental research model was used. The experimental group students are educated by means of the problem based learning and traditional teaching method is applied to the control group students. The conceptual understanding is measured by using the 'Inefficiency of Classical Physics Conceptual Comprehension Scale' (ICPCCS) and the critical thinking skills are measured by means of the 'Critical Thinking Attitudes Scale' (CTAS). As a result, it is extracted that both teaching methods have improved the conceptual understanding, however the conceptual understanding level of the experimental group students is found to be significantly greater than the control group. It is also clearly concluded that the mean scores of each step of the three-tier ICPCCS are significantly higher, in favor of the experimental group students. In contrary, the CTAS results designate that there is no significant progress on the critical thinking attitudes for both groups. The correlation analysis, on the other hand, indicates that the correlation between the conceptual understanding and the critical thinking is weak.

Keywords: Problem Based Learning, Quantum Physics, Conceptual Understanding, Critical Thinking, Classical Physics Insufficiencies.

Resumen

El objetivo de esta investigación es investigar los efectos del método de aprendizaje basado en problemas (PBL) en la comprensión conceptual (CU) y las habilidades de pensamiento crítico (CTS) específicamente en relación con la radiación del cuerpo negro, el efecto fotoeléctrico y la dispersión de Compton. A lo largo del estudio, se utilizó un modelo de investigación semiexperimental agrupado de control pretest-postest. Los estudiantes del grupo experimental son educados mediante el aprendizaje basado en problemas y se aplica el método de enseñanza tradicional a los estudiantes del grupo de control. La comprensión conceptual se mide utilizando la "Escala de comprensión conceptual de ineficiencia de la física clásica" (ICPCCS) y las habilidades de pensamiento crítico se miden mediante la "Escala de actitudes de pensamiento crítico" (CTAS). Como resultado, se extrae que ambos métodos de enseñanza han mejorado la comprensión conceptual, sin embargo, el nivel de comprensión conceptual de los estudiantes del grupo experimental se encuentra significativamente mayor que el del grupo control. También se concluye claramente que las puntuaciones medias de cada paso del ICPCCS de tres niveles son significativamente más altas, a favor de los estudiantes del grupo experimental. Por el contrario, los resultados de CTAS señalan que no hay avances significativos en las actitudes de pensamiento crítico para ambos grupos. El análisis de correlación, en cambio, indica que la correlación entre la comprensión conceptual y el pensamiento crítico es débil.

Palabras clave: aprendizaje basado en problemas, física cuántica, comprensión conceptual, pensamiento crítico, insuficiencias de la física clásica.

I. NTRODUCTION

Physics Education Research (PER) predominantly aims to create an improved atmosphere and environment in order to teach and internalize complicated concepts and laws of physics more effectively and permanently [1]. In this sense, enhanced teaching of physical concepts and improved conceptual understanding levels are very essential [2, 3, 4]. The conceptual understanding is especially very important, because the elementary aim of PER is not only to memorize physical concepts and laws but also to develop some useful attitudes and abilities that can be employed to solve certain daily life problems [5, 6, 7]. In order to improve the conceptual understanding, various approaches and methods were employed in the past and majority of them report some tiny progress [8, 9].

Critical thinking basically means that the thinking processes involves abilities such as reasoning, analysis and evaluation [10]. In addition, the critical thinking ought to be involving the ability of handling a topic in terms of many aspects and the ability of thinking on abstract issues and producing clear provisions that match common sense and scientific evidence. The critical thinkers can combine any data obtained by means of written or verbal expressions, observation, experimentation and reasoning and can easily produce clarity, logic, depth and reliability [11]. Improving CTS of the students have therefore been at the leading edge of the Educational Research and evidently seems to be even further important for physics students. Recently, a number of studies are published which report on how to improve critical thinking attitudes of physics students, however the issue is still raw and needs to be tackled in more detail [12, 13, 14].

Quantum Physics, on the other hand, embraces many abstract and difficult-to-understand principles, laws, and concepts. Therefore, teaching quantum physics requires more attention and effort in order to reach the desired conceptual understanding levels. A brief scrutiny shows that most studies underline noticeably slight improvements on the conceptual understanding [15, 16, 17]. The literature also expresses that this undesired result arises from the student difficulties of interpreting the concepts of quantum physics and difficulties of associating the quantum phenomena with the daily life. Additionally, misunderstanding of certain concepts, mistakenly planned quantum physics courses and some problematic teaching approaches basically lead to further problems on conceptual understanding [18, 19]. The other obvious reason of conceptual difficulties is due to fact that the quantum physics deals with exceptionally complicated behavior of the matter at atomic scales which cannot be observed by naked eyes.

In spite of some great progresses on educational research, most teaching activities over the globe, statically employ the traditional teaching approaches. In the traditional education, mostly hearing-based passive teaching activities are employed, limited instructional techniques are usually available and realistically speaking in-classroom communications and interactions are few and unidirectional [21]. The traditional educational processes also assume that all the students have similar qualifications, regardless of their personal skills and abilities. In this case, the students' skills such as creative thinking, critical thinking and problem solving cannot naturally be advanced [22, 23].

In order to overcome certain teaching difficulties in physics, Problem Based Learning (PBL), is recently employed by a number of efforts. PBL, is a student-centered approach, simply based on commencing the instruction with a clear problem case, carefully designed and directly related to the specific topic of interest with the aim of overcoming definite deficiencies of traditional teaching [24, 25, 26]. PBL approach typically employs students divided into groups of 3 to 5 students, having similar academic characteristics which is an important duty of the process [27, 28]. Following the grouping process, a real-life problem scenario is given to the students and they are supposed to identify the specific scientific problem within the scenario. This stage is very crucial and must be designed very carefully because, any faulty resolution of the problem could in fact result many problems and accordingly violate the entire process of teaching. In the next stage, the students are expected to formulate the group hypotheses, on the base of their preliminary learning and daily life experiences. The group students are next expected to identify the necessary specific scientific knowledge and also determine the resources they need to test these hypotheses [29]. At this phase, the students are supposed to study and discuss decisively to test the hypotheses, under the light of the knowledge obtained from the sources and to determine the correct scientific principle or law that may be the solution to the problem [30]. The students are, by doing so, expected to gain their own scientific knowledge and improve their conceptual understandings and critical thinking skills up to the desired levels [31, 32, 33].

Hence, the principle aim of this work is to investigate the effects of Problem Based Learning (PBL) on students' conceptual understandings and critical thinking skills relating quantum physics, specifically relating Black Body Radiation, Photoelectric Effect and Compton Scattering which are named as Inefficiencies of Classical Physics [20]. Main motivation of selecting this specific subject arises from the observation that majority of the students are essentially unable to relate the structure of quantum physics with their daily life and the students experience great difficulties to internalize and achieve conceptual comprehension.

II. METHODOLOGY

A. Research Problem Statements

The present research primarily focuses on resolving conceptual understanding and critical thinking; therefore, the following research problems are formulated in order to measure the effectiveness of our PBL experimental teaching sequence.

1. Does problem-based learning (PBL) approach create some advantages over conventional teaching relating conceptual understanding (CU), concerning inefficiencies of classical physics within Quantum Physics?

2. Does problem-based learning (PBL) approach lead to statistically significant progress concerning CTAS of prospective teachers?

3. What is the correlation between the stage points of ICPCCS before and after the application?

B. Research Design

The current work simply employs the well-known pretest-posttest control grouped semi-experimental model throughout the work. Independent variable of the research is determined to be the *teaching approach* with two variables; namely Problem Based Learning, activated in the experimental group and Conventional Teaching Method, activated in the control group. Dependent variables of the study, on the other hand, are Conceptual Understanding, and Critical Thinking. The conceptual understanding is measured with a three-tier conceptual understanding scale (ICPCCS) with definite sub-variables of academic achievement, classical answer and level of assurance. ICPCCS and CTAS are employed to measure the dependent variables by both carrying out at the beginning (pre-test) and at the end (post-test) of the actual teaching period.

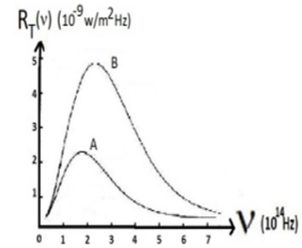
C. Measurement Instruments

C1. Insufficiencies of Classical Physics Conceptual Comprehension Scale (ICPCCS)

In this study, the conceptual understanding level of the students is measured by means of Insufficiencies of Classical Physics Conceptual Comprehension Scale (ICPCCS) which was applied as pre-test and post-test to both groups [34]. ICPCCS is designed as a three-tier conceptual comprehension scale, purely developed by the researchers. The Cronbach Alpha reliability coefficient of the final version of the scale was found to be 0,78. The ICPCCS has a total number of 20 items, specifically 8 questions related to the Black Body Radiation, 6 questions related to the Photoelectric Effect and 6 questions are related to the Compton Scattering. The figure 1 presents an exemplary item to give an idea about the scale.

The ICPCCS is comprised of three separate stages, namely multiple choice, classical answer and finally level of assurance. The first stage is designed to measure the actual knowledge of the student concerning a specific sub-topic. The second stage is the classical explanation phase and the students are supposed to write their classical answers on the marked item in the first stage. The final stage is about the knowledge assurance and the students are expected to reflect their level of confidence on the measured scientific knowledge. The second stage is specifically designed to determine whether the content of the response given in first stage is truly known or not, in the classical sense. The correct answer, given in the first stage, is normally expected to be supported by the correct classical answer in the second stage. By doing so, it is possible to determine the students to get the right answer by solely chance without having any conceptual understanding. Therefore, it is possible to prevent the negative effects on the accuracy of the research findings. The data obtained from the ISPCCS is analyzed in the following manner. Concerning the first stage, the correct answer is pointed by 1 and wrong answer by 0 points. In the second phase, totally correct explanation pointed by 2, partially correct answer pointed by 1 and totally wrong answer is pointed by 0. Table I presents the criteria that are considered for the evaluation of the second stage, the classical explanation stage.

1)
i.



The frequency-dependent variation of the spectral radiation power for the different substances A and B is as shown in the figure. Which of the following statements would be wrong?

a) The value of the maximum spectral radiation power of the radiation varies according to the type of material.
b) The temperature of substance B is higher.
c) In the case where the spectral luminosity of the substance A is at its maximum value, the wavelength of the radiation emitted is greater than the substance B.
d) The total radiation power of substance B is greater.

ii. Explain your answer.

iii. How confident are you?

a) totally confident b) partly confident c) confident d)not confident e) no confident at all

FIGURE 1. A sample item of the three tier ICPCCS. The scale has three phases; the first phase is a multiple-choice test; second stage is about classical explanations and the third stage is about personal knowledge confidence level.

Table I. The rubric employed for the evaluation of the classical explanation stage of the ICPCCS.

Classification	*Answering Details*	*Points*
Totally correct	Physical principles, equations, results and explanations are correct.	2
Partially correct	At least one of the physical principles, equations, interim processes, results and explanations is incorrect.	1
Wrong	None of the physical principles, equations and intermediate processes, conclusions and explanations are correct.	0

Concerning the third stage, the marks of 5, 4, 3, 2 and 1 are given to choices of 'totally confident', 'partly confident', 'confident', 'not confident' and 'no confident at all', respectively. The overall maximum score of the test is set to 160. ICPCCS is specifically and solely contains conceptual questions and to reach the correct answer they do not require any mathematical operations. In order to answer the questions correctly, it is crucial to know the relating mathematical equations in addition to some critical interpretations.

C2. Critical Thinking Attitude Scale (CTAS)

The critical thinking skills of the prospective teachers are genuinely measured by means of the Critical Thinking Attitude Scale (CTAS), developed by Özelçi and Saracoğlu (2017). The CTAS is employed as pre-test and post-test tools to observe the variations in critical thinking attitudes of the students [35]. The CTAS consists of a total number of 19 items and five sub-dimensions, namely request for information acquisition, self-regulation, inference, evidence-based decision making and reason-to-seek. The sub-scales have a Cronbach alpha internal consistency coefficients of 0.70, 0.64, 0.52, 0.54 and 0.56, respectively. The overall scale has a maximum score of 95 and a minimum score of 19 and the scale is expressed as to mostly be appropriate for the use of 17-25 years of age. The data obtained from the CTAS are simply evaluated by scoring the choices in the following form. Relating the positive items, totally agree 5, agree 4, partly agree 3, disagree 2, strongly disagree 1. Concerning the negative items, on the other hand, totally agree 1, agree 2, partly agree 3, disagree 4, strongly disagree 5.

D. The Samples

The sampling of the research was determined by using homogeneous sampling method which is a sub-branch of the purposive sampling methods, among nonprobability sampling design, since the application is carried out with students who have not previously taken the modern physics course [36, 37]. The sampling of the research is composed of a total number of 59 3rd grade students, 14 males and 45 females, who currently take the modern physics course for the first time, at the Department of Mathematics and Science Education. The students within the sampling have nearly same cognitive levels due to the reality that all the students are basically registered to the department based on their cognitive scores of national university entrance examination. Randomly selected class A is appointed as the control group with 29 students with 6 males and 23 females and in this group the lessons were done in the traditional way. Whereas, the Class B with a total number of 30 students, 8 males and 22 females, is chosen as the experimental group in which the lessons are conducted by means of PBL. The age range of the students within the groups is between 20- 23. In order to avoid the human factor effects, the same instructor carried out all the teaching procedures for both the experimental and the control groups and the teaching sequences are managed within the same period of time.

E. Implementation of the Problem Based Learning

The Problem Based Learning is naturally different from the conventional teaching approaches, therefore the experimental group was educated beforehand about the PBL approach and questions about the approach were effusively answered. In this sense, two separate units were effectively thought and each unit was completed in a week. In the study, the PBL approach was performed within the well-known 5E teaching model. The 5E teaching model enables the student to use their knowledge and skills actively, additionally increases curiosity and genuinely responds to the expectations. The 5E approach consists of five separate stages, namely Engagement, Exploration, Explanation, Elaboration and Evaluation and the stages are briefly applied in the following manner [38, 39, 40, 41].

Engagement: The main aim, at this stage, is to attract the attention to the topic and to enhance the curiosity and the motivation. To serve this aim, the students were initially presented a video specifically selected to match the preliminary knowledge of the students. Then the students were asked to resolve the event and following some five-minute brainstorming, the event was briefly explained in the classroom. Specifically relating the black body radiation, a heated iron and its thermal camera images were displayed. Concerning the photoelectric effect, a video was shown in which the closing of the plants was detected when a light was placed on a loaded electroscope. In Compton scattering, a video about the breakage of light through a metal surface was shown.

Exploration: This phase of the application is very important in the sense that the students are truthfully exposed to the problem situation that is, in fact, the scenario or problem case prepared quite carefully beforehand. The students, within the groups, are kindly asked to discuss and extract the scientific problem and accordingly define it with a clear scientific statement. The scenarios distinctly involve a daily-life for each subject, carefully designed by considering the objected gains. Additionally, in order to facilitate the students' visualization of the event, relevant images were presented together with the scenarios. Particular attention has been paid to the inclusion of the events in which classical physics could not explain. Naturally three separate scenarios were prepared for the three sub-topics namely, black body radiation, photoelectric effect and Compton scattering.

Explanation and Elaboration: At these stages, the students are asked the question of ‘Which specific laws of physics can be employed to resolve the events in the scenario?’. After a while, the students were supported with appropriate sources and supposed to explore and solve the problem case. Students were given some time for discussions in the groups and for deepening the search on resources. After each group prepared their own common answer, they were asked to explain their answers and the reasons of this answers to the class. At the end of the stages, all the class and instructor were expected to have exchanged their ideas and determined their exact and correct answers.

Evaluation: This is the phase where the student's post-training knowledge level is revealed. At this stage, each group was given some short problems relating the subject in order to measure the students’ knowledge gain. These problems were later solved by the educator in a similar way to the previous stage.

III. RESULTS

In order to answer the research problems, the data is analyzed step by step by means of the SPSS 22.0. Independent samples t-test was executed to investigate the statistically meaningful relationship between means of experimental and control group students relating both CTAS and ICPCCS. The independent samples t-test compares the means of two independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different [42]. Paired sample t-test was executed to compare the means obtained from the scales before and after the application separately for each group. The paired samples t-test compares the two means that are obtained from the same individual object. The two means typically represent two different but related conditions or units [43]. Throughout the statistical analysis, the results were tested with a significance level of 0,05.

A. Descriptive Statistics for the ICPCCS and CTAS

In order to investigate the measurement results plainly the mean values of the pre- and post-tests are computed for the both measurement tools. Standard descriptive statistics is employed in order to calculate the mean values of for both scales, namely ICPCCS and CTAS before and after the actual teaching activities. Table II simply shows the data on ICPCCS together with all three phases namely, multiple choice, classic explanation and knowledge assurance. Table II also shows the results of CTAS for pre- and post-measurement scores. The score ranges of the ICPCCS are, 20-160 for the overall, 0-20 for the multiple choice, 0-40 for the classical explanation and 20-100 for the assurance. The possible score range for the CTAS is 19-95.

Table II. Descriptive statistics for students' conceptual understandings and critical thinking attitudes.

Scale	*Experimental Group*		*Control Group*	
	Pre Mean	*Post Mean*	*Pre Mean*	*Post Mean*
ICPCCS Total	59,87	101,17	56,17	78,72
Multip. Choice Stage	8,87	13,07	8,55	10,62
Classical Exp. Stage	1,70	17,17	1,48	7,31
Assurance Stage	49,00	69,67	46,14	60,79
CTAS	72,87	75,13	76,66	76,86

B. Comparison of the Means before the Application

In order to extract information on the pre-application readiness levels of the experimental and conventional group students, the independent samples t-test is basically employed and the means are simply compared statistically. Table III shows if there is a statistically meaningful difference on the average values of the variables, which are conceptual understanding and critical thinking skills, of the two groups before the actual teaching activities. The table III gives the comparison of the overall scores, in other words, the results of the independent sample t-test, together with the sub-stages of the ICPCCS and CTAS.

Table III. Independent samples t-test results comparing pre-test means of the experimental and control groups.

Scale	*p (pre-test means of the groups)*
ICPCCS total	0,297
ICPCCS multiple choice	0,502
ICPCCS classic explanation	0,646
ICCPS assurance	0,386
CTAS	0,051

Table III clearly demonstrates that there is no significant difference between the two groups in terms of conceptual understanding and critical thinking skills before the application.

C. Comparison of the Means of the Pre and Post Measurements

In order to investigate the progress, if any, within the individual group, paired sample t tests are carried out between the means of teach group before and after the teaching activities. The t-test results are plainly shown for the experimental and traditional groups separately in the Table IV.

Table IV. Paired sample t-test results comparing pre-test and post–test means of the two groups for both measurement tools, ICPCSS and CTAS.

Scale	*Experimental Group* *p (pre and post-test means)*	*Control Group* *p (pre and post-test means)*
ICPCCS total	0,000*	0,000*
ICPCCS multiple choice	0,000*	0,000*
ICPCCS classic explanation	0,000*	0,000*
ICPCCS assurance	0,000*	0,000*
CTAS	0,286	0,887

** The difference is significant*

Table IV clearly demonstrates that the problem-based learning method and the traditional method have a statistically significant effect on the students' conceptual comprehension levels (ICPCCS) on both total scores and stage scores. However, no statistically significant effects are detected for both groups concerning critical thinking attitudes (CTAS).

D. Comparison of the Means after the Application

The ultimate aim of the research was to detect statistically meaningful difference between the problem-based group and the conventional group relating the conceptual understanding (ICPCCS) and critical thinking skills (CTAS) of the prospective teachers at the end of the overall teaching activities. In order to detect the meaningful difference, the independent sample t-test is employed for both measurement tools together with the sub-stages and the final results are presented in the table V.

Table V. Independent samples t-test results comparing the means of the two groups after the application for both ICPCCS and CTAS.

Scale	*p (post-test means of the groups)*
ICPCCS total	0,000*
ICPCCS multiple choice	0,000*
ICPCCS classic explanation	0,000*
ICCPS assurance	0,005*
CTAS	0,361

**The difference is significant*

The table V noticeably indicates that there are significant differences between the group means in terms of conceptual understanding/ICPCCS) concerning both total score and stage scores, in favour of the experimental group. However, no statistically significant difference is detected between the two groups' critical thinking (CTAS) post-test scores.

E. Correlation between ICPCCS Stage Scores

Pearson correlation analysis was executed to determine the relationship between the responses of the experimental group and the control group students to the ICPCCS stages before and after the educational processes. The results of the analysis are shown in the Table VI.

Table VI. Pearson correlation analysis results of ICPCCS stage points before and after the educational processes. In the table, i denotes the multiple-choice scores, ii denotes the classic explanation scores, and iii used for the assurance scores.

	ICPCCS (i-ii)	*ICPCCS (i-iii)*	*ICPCCS (ii-iii)*
Pre-test (exp. group)	0.196	-0.018	0.295
Post-test (exp.group)	0,589	0,161	0,410
Pre-test (cont. group)	0,178	0,120	0,132
Post-test (cont.group)	0,649	0,622	0,680

Table VI briefly shows that the relationship between the first and the second stages for both groups are weak before the application and became strong after the application. It can also be understood that the relationship between the first and the third stage scores and also the relationship between the second and third stage scores of the control group students are weak before the educational activities, however becomes strong after the educational activities. Additionally, a negative relationship is detected between the first stage and the third stage scores of the experimental group before the application and this relationship turns out to be positive but weakly after the education. The relationship between the second and third stage scores of the experimental group is moderate both before and after the application.

IV. DISCUSSIONS AND CONCLUSION

This part of the paper focuses on interpreting and discussing fundamental outcomes of the research and on expressing major implications.

The first research problem statement was built on the conceptual understanding. The employed measurement tool, ICPCCS, has obviously three separate phases and overall means demonstrate the total conceptual understanding levels of the students. The mean value results, shown in the table II, plainly shows that the overall conceptual understanding has been improved by % 25,8, with respect to the overall score of 160, for the problem-based group students whereas the change for the conventional group students is only % 14,1. The clear % 11,7 difference can straightforwardly be attributed to the success of the problem-based learning approach. The corresponding t-test results, searching for any statistically meaningful difference with a confidence level of 0.95, is given in the table V. This clear result is obviously supported by the outcomes of the t-test given in the table V. *Therefore, the answer concerning the first problem statement, is that the problem-based learning has a meaningfully positive effect on the conceptual understandings compared to the traditional teaching method.* This pure result is consistent with some previous studies carried out on the problem-based teaching method [44, 45]. The purpose of the three-tier scale (ICPCCS) was to search about not only the academic success levels obtained solely from the multiple choices but also investigate student responses concerning detailed justification of the first stage by means of classical explanations and additionally their confidence levels on their specific answers. In order to determine the detailed effects of the PBL, we simply focus on individual stages. The brief comparison of the means of the experimental and conventional group students for each stage gives %12,3 difference for the multiple choices, %24,7 difference for the classical answers and finally %8,9 difference for the assurances, all in favour of the experimental group students. This result is, of course, supported by the t-test results given in the table V. *Therefore, one can underline that PBL approach creates a much better atmosphere than the traditional teaching for a better understanding and for internalising the actual knowledge*.

The second research problem statement was about the critical thinking attitudes of the prospective teachers. At this stage, it is basically aimed to search about any meaningful differences between the two groups relating CTAS. The means of the two groups, shown in the table II, for both pre- and post-measurements are nearly the same. The exact difference between the post and pre measurements for the experimental group is 2,26 points and 0,02 points for the conventional group students. The independent samples t-test results, shown in the table V, accordingly demonstrate no meaningful difference on critical thinking attitudes (CTAS) between PBL method and conventional teaching method. *Therefore, concerning the second problem statement of the research, it can be concluded that both methods have no significant influence on students' critical thinking attitudes.* This specific result is also consistent with some previous studies [46, 47]. However, it ought to be stated that some studies had shown that PBL has positive effects on critical thinking attitude skills [48, 49].

In order to obtain an answer for the third problem statement, the Pearson correlation analysis is executed. As a result of the analysis, it clearly is observed that all the correlations between ICPCCS stage scores, following the educational activities, is strong except the intermediate relationship between the first and the third (i-iii) stage and the second and the third (ii-iii) stage scores of the experimental group. The average increases of the correlation coefficients are basically calculated to extract a general interpretation for both groups and found that the average increases are 0.228 and 0,507 for the experimental and control group students, respectively. *As a conclusion relating the third problem statement, it can be stated that the correlation between the stage scores of the ICPCCS is increased significantly for both groups however with a greater progress for the control group students.* Combining the correlation results with the statistical t test results leads to the conclusion that the statistically significant increase in the conceptual understanding is not only caused the increase in one stage, but almost equal increases in all three stages. This is important an important point for the reliability of the results achieved throughout the work. Hence, one can express that the results obtained from the correlation analysis and t test are consistent, showing that the ICPCCS is a useful and reliable scale.

This present study manufactured some important conclusions that are partially supported by the findings of previous studies, in accordance with the above mentioned literature. In addition, the results are important to investigate the effectiveness of PBL approach on students' conceptual understanding specifically on quantum physics. The present work is also important in the sense that, to our knowledge, no previous research on quantum physics employing PBL appearing. One of the biggest obstacles about teaching quantum physics, is the relentless desire to establish a relationship with the daily life. According to the present results, students can establish a higher conceptual understanding based on problem-based teaching, however it seems impossible to teach quantum physics by only using PBL to gain some higher level of conceptual understanding. Unlike classical mechanics, quantum physics contain countless situations and phenomena that students would have difficulty in visualizing and understanding. Therefore, in the PBL process, educators need to deal specifically with each group to ensure that they fully understand the problem.

The negative results obtained on critical thinking, on the other hand, may due to be the inadequacy of the educator or short implementation period of time. Critical thinking attitude is related to the affective domain and, in general, significant progress on the emotional domain is reportedly very tricky due to the certain psychological and mental processes. The advancement and the control of the mental processes challenge, in fact, all the scientific community and therefore exceptionally hard to achieve. A meaningful effective study on critical thinking may require longer time, therefore, the researchers planning to work on critical thinking may be advised to arrange their instruction for a longer period of time.

Obviously, the traditional teaching methods have emerged decades ago in accordance with poor physical and educational conditions of those years. It is important, at this stage, to underline that, taking into account of recent exceptional technological developments, it is nowadays indispensable to abandon traditional methods and very reasonable to move certain innovative methods of teaching.

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