EFFECT OF PROBLEM-BASED LEARNING INSTRUCTION ON SECONDARY SCHOOL PHYSICS STUDENTS IN UNDERSTANDING OF ELECTROMAGNETIC WAVES

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Abstract

The study of electromagnetic waves helps physics students acquire knowledge which is relevant to solving problems in their daily life. Helping students maximize knowledge acquisition has become key in science education research. The aim of this study was to analyze the effect of Problem-Based Learning Instruction on physics students' understanding of electromagnetic waves. A quasi-experimental, non-equivalent pretest-posttest control group design was used in this study with PBL instruction as the intervention. This study involved 419 students from 16 public and private secondary schools in Mitooma district-South Western Uganda. Descriptive statistics, paired and independent samples t tests were used in data analysis. Findings from the study indicated that PBL did improve significantly students' understanding of electromagnetic waves more than traditional methods with those exposed to both pretest and posttest scoring significantly more than those exposed only to the posttest. However, students still exhibited difficulties such as arranging the electromagnetic spectrum in order of either increasing or decreasing wavelength/frequency. We recommend that school officials devise means of supplementing book libraries with internet connected computers to help students visualize the nature of electromagnetic waves to enhance their understanding of intended concepts.

Keywords: *understanding, electromagnetic waves, physics' students, Problem-Based Learning instruction*

State of literature: Much as there are research studies in science (physics) education that test the effectiveness of Problem-Based Learning instruction, very few exist that analyze its role in enhancing students' understanding of electromagnetic waves.

Contribution to literature: The study compares the change in the scores on the electromagnetic waves between physics students instructed using Problem-Based Learning and those instructed using traditional methods. The study further identifies students' difficulties with electromagnetic waves.

The role of Science, Technology, Engineering and Mathematics (STEM) in general and Physics in particular is key in achieving sustainable development in any modern world (Uwamahoro, Ndihokubwayo, Ralph, Ndayambaje, 2021).

The Ugandan Government through the Ministry of Education and sports adopted a Competency Based Curriculum (CBC) for lower secondary schools in 2020 with the aim of developing among learners employable skills that are competitive in the job market (National Curriculum Development Centre, 2020).

Among science subjects, physics is considered by students as the most difficult despite its numerous applications in telecommunications, energy, architecture, engineering, electricity production and transmission, construction, and transport (Duncan & Kennett, 2014; Ling, Sanny, & Moebs, 2018); being a source of employment for people who are in related occupations such as teachers, scholars, and other researchers; a base for other academic disciplines such as biology, and chemistry; and its ability to facilitate students in developing logical skills needed for problem solving in various dimensions of life they encounter (Eijkelhof & Kortland, 1998).

Students tend to have difficulty dealing with various concepts of physics including electromagnetic waves - waves produced by the motion of electrically charged particles and can travel through empty space as well as through air and other substances (Özdemir & Kargi, 2011). Inability of students to correctly deal with these concepts has been linked by previous researchers to the teaching methods employed which mostly involve teachers lecturing in front of students with material mainly derived from textbooks (Dori & Belcher, 2005). These methods diminish students' opportunity to develop free exchange of ideas and do not foster active learning (Dori & Belcher, 2005). A study by Hake (1998) indicated that involving students in interactive engagement strategies improves their conceptual understanding. As pointed out by Wittmann (1998), having an insight into student understanding of concepts taught in the classroom provides a ground to create curriculum materials that are more effective in improving a student's actual understanding. Therefore, driven by the need to change the prevalent passive teaching mode and to involve students in active learning, Problem-Based Learning (PBL) instruction becomes a prerequisite method for this cause.

Problem Statement

The science curricula for secondary schools globally not only targets the understanding of scientific contents, laws, theories, methods and procedures used by scientists understanding of scientific contents, laws, theories, methods and procedures used by scientists, but also the understanding of how scientific knowledge is developed and used (Ryder et al., 1999). However, reports on national examinations in Uganda have identified lack of this understanding majorly among physics students, pointing out various misconceptions with electromagnetic wave concepts despite their importance in health and technological developments (Uganda National Examination Board, 2016; 2017). These reports further identify that students generally dodge questions on waves and those who attempt them fail. Previous researchers such as

Tongchai et al. (2008) and national examiners have associated this problem with teachers' failure to employ methodologies that promote activities in which students develop understanding of these scientific ideas. As a result, students may tend to drop science subjects as they go to higher levels contributing to lack of skilled labor among Science, Technology, Engineering and Mathematics (STEM) fields. In response, the Government of Uganda in January 2020 adopted a competence-based curriculum (CBC) to enhance students' skills, knowledge and development of self confidence in problem solving. As a move to improve students' learning outcomes, this study seeks to assess the effectiveness of Problem-Based Learning (PBL) as a CBC pedagogy in enhancing students' understanding of wave concepts in physics among secondary schools in Western Uganda.

Aim of the study

This study aimed at analyzing the effect of Problem-Based Learning instruction on physics students' understanding of electromagnetic waves.

Specific objectives: Students' understanding of electromagnetic waves was assessed using two objectives: To compare the change in scores on the electromagnetic wave conceptual survey between physics students instructed using Problem-Based Learning and those instructed using traditional methods; To analyze students' difficulties with electromagnetic wave concepts.

Research questions: Is there a difference in the change in scores on the electromagnetic wave conceptual survey between physics students instructed using Problem-Based Learning and those instructed using traditional methods? What are the students' difficulties with electromagnetic waves?

Hypothesis: There is no statistical significant difference between the change in scores on the electromagnetic wave conceptual survey between physics students instructed using Problem-Based Learning and those instructed using traditional methods; There is no statistical evidence of students' difficulties with electromagnetic wave concepts.

Review of Literature

Students' Difficulties with Electromagnetic Wave Concepts: Students globally perceive the study of waves as difficult, abstract, uninteresting, and as a discipline suitable only for exceptionally talented and gifted learners (Erinosho, 2013). In the study conducted by Tabor-Morris et al. (2017), teachers at secondary level pointed out that students mis-identify radio waves as longitudinal sound waves instead of transverse electromagnetic waves. Student interpretations do not focus exclusively on the event nature of wave phenomena but instead give an object-like description (Wittmann, 2002). Richardson (2004) discovered that many students tend to concentrate on problem-solving strategies without minding about being attentive to the underlying concepts; instead of endeavoring to construct conceptual understanding of waves in physics in order to solve wordy problems, students use formula-centered translation strategies. If students' difficulties are not addressed in early enough, they can persist, and become worse, when the topic appears again in a more advanced course (Ryan, Wilcox & Pollock, 2018).

Traditional Methods of Teaching: Presently, the classroom mode of instruction followed by teachers is considered a critical parameter in influencing learning outcomes (Isac et al., 2015). Teachers' choice of classroom methods is usually based on the kind of teaching and learning they experienced as school students, the methods promoted during teacher training, those specified in the school curriculum, from fellow teachers and from learning theories (Westbrook et al., 2013); the appropriateness of these methods depends on the goal, students' backgrounds and needs, available materials, and the teacher's personality, strengths, and style (Jacobsen et al., 2009).

Traditionally, teacher-centred methods commonly referred to as the conventional instruction have been highly employed where the teacher retains full control of the classroom and its activities (Mpho, 2018) and students remain passive recipients of knowledge (Karamustafaoglu, 2009). Example of conventional instruction according to Hill (2002) include direct instruction/chalk and talk, which describes a variety of whole class expository teaching techniques. Teachers who employ this approach concentrate on the content of teaching and on what they do in teaching by focusing on how to organize, structure and present the course content in a way that is easier for the students to understand (Sari et al., 2006). Direct instruction takes the form of lectures and demonstrations. Expository techniques in this approach emphasize building on students' prior knowledge and having them assimilate information by listening (Hill, 2002). Richardson (2004) found out that in most cases, teachers tend to use traditional lecture method which overemphasizes problem-solving over conceptual understanding. With this approach, many students according to Mioković et al. (2012) may be able to apply the appropriate formula when answering questions as a result of memorization, but are fond to lack understanding of the basic principles. More so, if the teacher dominates during the teaching and learning process, then student are more likely to lose sight of their major goals as compared to when they are constructing their own knowledge (Mpho, 2018)

However, recent curriculum reforms are advocating for an incline from conventional instruction approaches to active learning/learner-centred approaches that encourage students to participate during learning (Westbrook et al., 2013; Lewin, 1992). Students in this approach get actively engaged in activities that encompass analysis, synthesis and evaluation besides developing skills, values and attitudes (Karamustafaoglu, 2009). Active learning deals with learning activities in which students are given considerable autonomy and control of the direction of learning activities including experimentation and problem solving instruction (Jacobsen et al., 2009).

Problem Based Learning Instruction

The education System nowadays focuses on training learners in such a way as to possess skills that enable them to work in various situations. Education philosophers such as pragmatists propose that humans learn through a process of learning by solving real problems which they face in their day to day life (Richardson, 2003). Based on these philosophies, problem based learning was developed from the constructivism school of thought where learners work on their own to generate new knowledge and understanding (Awan, Hussain & Anwar, 2017).

According to Allchin (2013), Problem-Based Learning instruction is a teaching method where students engage in solving real life problems. PBL engages students in intriguing real and relevant intellectual inquiry and allows them to learn from these life situations (Fogarty, 1997). In PBL, students start by solving problems and actively get involved in learning as they develop new knowledge within the context in which it is to be used (Chin & Chia, 2004). They work in groups and are expected to work collaboratively to initially identify or create a problem as presented in the situations or contexts and subsequently propose solutions to the problem using any and all synchronous and asynchronous tools available (Savin-baden, 2007). The role of teacher in in PBL is to facilitate the process of problem solving (Chin & Chia, 2004) by monitoring discussion and intervening when appropriate, asking questions that probe accuracy, relevance, and depth of information and analyses, raising new issues for consideration, and fostering students participation (Allen et al., 2011). PBL promotes the development of critical and reflective thinking about the process itself as well as emotional aspects such as curiosity (Sadeh & Zion, 2009). Thus, PBL is taken as an effective methodology in the teaching of waves since it may enhance emotional domain of students' learning process, improve their performance and foster a better knowledge retention (Allen et al., 2011). Additionally, students who learn under PBL instruction are able to share their opinion with others, use different approaches to analyze situations and explore ways of solving problems (Orozco & Yangco, 2016). They are also able to reflect explicitly on their experience and thereby deepen their understanding of scientific practices (Allchin, 2013).

Methodology

Study setting and design: The study was carried out in secondary schools in Mitooma district (0.61930S, 30.02030E) -South-western Uganda with Mbarara as the regional city. The study was carried out from December 2020 to February 2021 among grade 13 physics students. It employed a quantitative quasi-experimental research design. It was quasi-experimental due to the fact that conducting true experiments on human beings is not possible. The study was non randomized pretest-posttest control group design.

Sampling strategy

This study was conducted from October 2020 to February 2021. Among the Standard Operating Procedures to curb down the spread of Covid-19, all candidate classes were made boarding. More to that, apart from two secondary schools which are single-girls, the rest of the secondary schools in Mitooma district are mixed (both girls and boy). Therefore, simple random sampling was employed to select the participating schools. Intact classes were used as they existed in the schools.

Training of physics teachers in PBL process

Physics teachers from the selected schools first attended a six-hour two day professional training in PBL facilitated by the authors. Table 1 gives the training program. By the end of the training, the participants were able to draft some problems on the concepts of electromagnetic waves using online resources and text books.

Table 1 - The Two-day Schedule for the Physics Teachers' Training in PBL

Time (Hours)	Activity	Facilitator	Supporting materials
Day 1			
8:00-8:30	Arrival and registration	Research assistant	Registration Forms
8:30-9:00	Individual introduction	All members	Attendance sheets
9:00-9:30	Opening remarks (sharing training objectives)	Training leader	Power point slides
9:30-10:00	Pre-test	All Participants	Survey forms
10:00-10:30	Commercial Break	All members	
10:30-11:30	Origin of PBL	Training Leader	Power point slides
11:30-12:30	Importance of PBL in Teaching and Learning	Training Leader	Power point slides
12:30-13:00	Open discussion	All members	Flip charts
13:00-14:00	Lunch Break	All members	
14:00-15:00	Formulating a PBL question	Training Leader	Power point slides
15:00-16:00	Class-activity - on Formulating PBL questions	Facilitated groups and SESEMAT trainer	Flip charts
16:00-16:30	Summary of the day's activities and closure	Training leader	Power point slides
Day 2			
8:00-8:30	Arrival and registration	Research assistant	Registration forms
8:300-9:30	Steps followed in present a PBL lesson	Training Leader	Power point slides
9:30-10:00	Class activity- drafting PBL lessons	Participants and SESEMAT trainer	Flip charts
10:00-10:30	Commercial break	All members	
10:30-13:00	Group presentations on PBL lessons	Group secretaries	Flip charts
13:00-14:00	Lunch break	All members	
14:30-15:00	Assessing a PBL lesson	Training Leader	Power point slides
15:00-15:30	Open discussion	Participants	Flip charts
15:30-16:00	Summary of the day's activities	Training leader	Power point slides
16:00-16:30	Post-test and closure	Participants and Training leader	Survey forms

Data collection

The process of data collection followed Solomon Four-Group Design (Creswell, 2014). An electromagnetic Waves Conceptual Survey composed of problems on light as an electromagnetic wave was designed basing on that used by Tabor-Morris et al. (2017) in their study entitled "Radio Wave Errors: Students Mistaking Radio Transverse Electromagnetic Light Waves as Longitudinal Waves" was used for this study. This survey was a pretest-posttest multiple choice with PBL as the intervention and it was distributed with the help of the schools' physics teachers. It contained items similar to those often tested on electromagnetic waves by the Uganda National Examination Board (UNEB). To ensure validity, the survey items were presented to two research experts for their independent views on each item. The number of items considered valid by both experts (n=15) was divided by the total number of items on the survey (N=19) and it yielded a validity index of 0.79 hence considering the items valid. For reliability, the survey was pilot-tested. For internal consistency, Cronbach's Alpha Coefficient Based on Standardized Items was computed and obtained as 0.71.

In addition, to determine if there was a difference between the test re-test scores obtained in the pilot study, the scores were subjected to a paired t test and the relationship between them was found to be non-significant (p=0.154) at 95% Confidence Interval (CI) of the Difference. Therefore, the instrument was considered reliable for data collection.

Intervention

Participants in the experimental group were instructed in the concept of 'light as an electromagnetic wave" using PBL as the intervention with teachers basically guiding students into using computer simulations, charts and experiments to understand the concepts and solve the pre-given problems that had been prepared by teachers after the PBL training. The students under PBL were required to first workout the problems in groups of 5 to 6 students before converging as a class to make group presentations. Teachers in the control group (who had not been trained in PBL) basically were dictating notes with little explanation to students. Teachers in the control group hardly involved students but referred them to past papers for self-trial questions. From the teachers' schemes of work, the concepts of electromagnetic waves had been allocated 6 hours (2 hours per week). Before instruction took place, participants from experimental and control groups (based on schools) were randomly subdivided each into two groups in which one of the groups was given the pre-test. After instruction, all participants were given a post-test.

Data Analysis

The responses of the participants were first coded and then fed into the computer using the Statistical package for Social Scientists (SPSS) software version 20.0. Skewness and Kurtosis were computed to check for homogeneity and normality of the results. Analysis of the change in students' scores on the survey was done using the Paired- and Independent-Samples T tests. To determine students' difficulties with electromagnetic waves, the difficulty index (P) was computed from dividing the number of students who answered a single question correctly by the total number of students who attempted the question was used. Usually, P should be in the range of $0.2 \leq P \leq 0.8$. If it is more than 0.8, the item is considered to be too easy for discriminating between students, and if it is less than 0.2, the item is taken to be too difficult (Ding, 2006). In this study, the values of P were averaged to obtain the mean difficulty index $(\overline{P})$ which shows how well a particular group of students understands a given concept.

Ethical consideration: Ethical clearance was first obtained from University of Rwanda ethical clearance committee and then authorisation to conduct research in secondary schools in Uganda was obtained from the permanent secretary-Ministry of Education and Sports, Uganda. Informed consent was obtained from participants who were assured of confidentiality and anonymity of their responses.

Presentation and Discussion of Results

This section presents and discusses the results of the study in relation to the objections under investigation. In the first case, the results were investigated for homogeneity and normality as presented in Tables 2 and 3.

Table 2 : Levene's test of homogeneity of Variances using One way ANOVA

Groups	Score	Levene Statistic	df_1	df_2	p
Experimental versus Control	Pretest	0.594	1	239	0.442

From Table 2, homogeneity between the experimental and control groups was such that for the pretest scores, the values for Levene Statistic df_1, df_2, and p were 0.594, 1, 239, and 0.442. Therefore, it can be concluded that the groups used in the study were homogenous ($p>0.05$) hence comparable.

Table 3 : Normality of both pretest and posttest scores

Test	Mean	Std. Error	Median	Mode	Variance	Std. Deviation	Interquartile Range	Skewness	Std. Error	Kurtosis	Std. Error	Z score on Skewness	Z score on Kurtosis
Pretest	3.33	0.092	3	3	2.027	1.424	2	0.545	0.157	0.321	0.314	3.471	1.022
Posttest	9.68	0.141	10	13	8.290	8.29	5	-0.17	0.119	-0.86	0.238	-1.429	-3.613

From Table 3, the Mean, Median, Skewness and Kurtosis were 3.33, 3, 0.545, and 0.321 in the pretest scores; 9.68, 10, -0.17, and -0.86 in the posttest scores respectively. The Z score on Kurtosis in the pretest was 1.022 and in the posttest, Skewness and Kurtosis were -0.17 and -0.86 respectively. More so, Q-Q plots for pretest and post test scores were also plotted as shown in Figures 1 and 2.

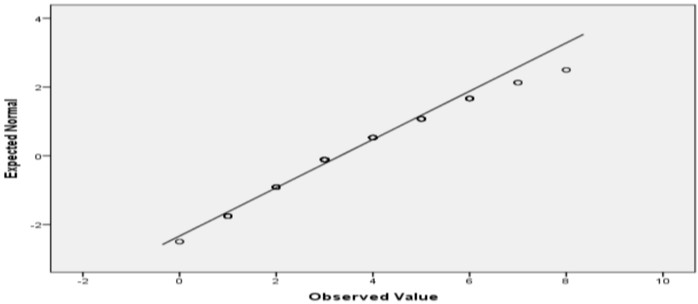

Figure 1 : Normal Q-Q Plot of Total Score in Pretest

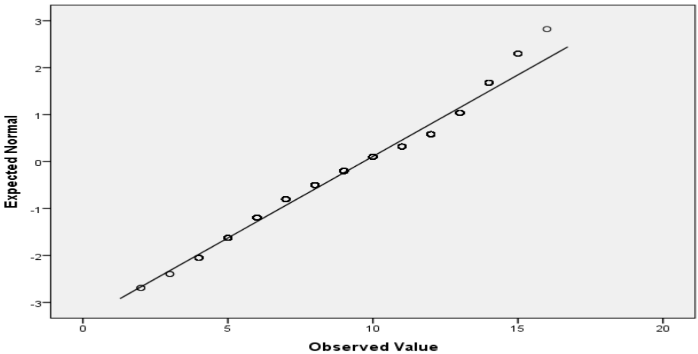

Figure 2 : Normal Q-Q Plot of Total Score in Posttest

Since the values of the mean and median in both pretest and posttest in Table 2 were approximately equal, the values of Skewness and Kurtosis were below 2 and 4 respectively, the pretest Z score on Kurtosis was in the range of ± 3.29, and the points on the Q-Q Plots in Figures 1 and 2 for both pretest and posttest were close to a straight line, the data was considered to some extent normal and hence capable of further statistical analysis.

In addition, participants' bio-data was checked using Pearson Correlation (*r*) and the 2-tailed significant value (*p*) to see if it influenced the study findings as presented in Table 4.

Table 4 : Influence of participants' bio-data on study findings

Score	Gender of students		Age of student in years		Subject combination		Status of school		Ownership of the school	
	p	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*
Pretest	0.001	0.988	-0.130	0.055	0.083	0.199	0.017	0.795	-0.005	0.944
Posttest	-0.007	0.892	-0.054	0.271	-0.045	0.357	0.165	0.061	0.044	0.364

From Table 4, the value of *r* and *p* were in the range of -0.130 to 0.083 and 0.055 to 0.988 in the pretest; -0.054 to 0.165, and 0.061 to 0.892 in the posttest. Much as Table 4 indicates that there was a relationship between participants bio data and scores on the survey, the influence was non-significant as the p value in all cases was greater than 0.05.

Change in the scores on the electromagnetic wave conceptual survey between students instructed using PBL and those instructed using traditional methods

To determine whether PBL instruction caused a more significant change is physics students' scores on the electromagnetic wave conceptual survey compared to the traditional methods, the paired samples t-test and MANOVA (Wilks' Lambda T) were used on participants who did both pretest and the posttest. In confirmation of the tests, the effect size-Cohen's D and Partial Eta Squared were also determined and the outcome is presented in Tables 5 and 6. The parameters used are such that M_1 and M_2 represent the mean scores in the pretest and posttest, M the paired mean difference, δ the paired standard deviation, e the paired standard error mean, t the t values, df the degrees of freedom, and p the 2-tailed significant values.

Table 5 : Paired Samples T-Test and effect size for the scores on the electromagnetic wave conceptual survey between students instructed using PBL and those instructed using traditional methods

Group	Mean		Paired Differences					t	df	p	Cohen's D
	M_2	M_1	M	δ	e	95% CI of the Difference					
						Lower	Upper				
Experimental	10.5	3.29	7.214	2.295	0.217	6.784	7.644	33.261	111	0.00	3.14
Control	9.72	3.36	6.357	3.464	0.305	5.753	6.96	20.844	128	0.00	1.83

From Table 5, the outcome of the paired samples test between posttest and pretest scores was such that for experimental group, M = 7.214, t (111) = 33.261, p = 0.000, Cohen's D = 3.14; while for the control groups, M = 6.357, t (128) = 20.844, p = 0.000 and Cohen's D = 1.83 respectively.

Table 6 : Summary of MANCOVA comparing the change in the scores on the electromagnetic wave conceptual survey between students instructed using PBL and those instructed using traditional methods

Group	Wilks' T	F	Hypothesis df	Error df	p	Partial Eta Squared (η^2)
Experimental	0.040	1289.081	2	108	0.000	0.960
Control	0.061	983.948	2	127	0.000	0.939

Results in Table 6 showed that there were significant differences between the pere-test and posttest scores in both the experimental (Hotelling's T = 0.040, F (2,108) = 1289.081, p = 0.000, $\eta^2 = 0.960$) and control groups (Hotelling's T = 0.061, F (2,127) = 983.948, p = 0.000, $\eta^2 = 0.939$.

Table 7 : Independent Samples T-Test for post-test scores

Group	Experimental group				T-Test for Equality of Means		
	N	M	δ	e	t	df	p
Experimental	209	10.3	2.594	0.179	4.472	408.25	0.000
Control	210	9.07	3.021	0.208			
Given both pretest and posttest	239	10.09	2.795	0.181			
Given only posttest	180	9.14	2.908	0.217	3.362	377.352	0.001

Considering Table 7, t (408.25) = 4.472, p = 0.000 between experimental and control groups, while between those given both pretest and posttest and those given only posttest, t (377.352) = 3.362 and p = 0.001.

Table 8 : Summary of ONE WAY ANOVA comparing difference in scores of physics students on the electromagnetic wave conceptual survey

Group	Sum of Squares	df	Mean Square	F	p
Experimental versus control	158.471	1	158.471	19.985	0.000
Given both pretest and posttest versus given only posttest	92.463	1	92.463	11.432	0.001

When the post-test scores for both experimental and control groups were compared (Table 8), they yielded a p value of 0.000. On the other hand, the difference between the posttest scores for participants who were exposed to both pre-test and post-test and those exposed only to the post-test test gave a p value of 0.001.

From Table 8, there was a statistical difference in the posttest scores experimental and control groups (p=0.000); additionally, the difference was also statistically significant for participants exposed to both pretest and posttest and those exposed only to the posttest test; and the difference in the scores was also significant (p =0.001) since the p values were less than 0.05.

Physics students' difficulties with electromagnetic wave concepts

In the post-test, the highest, the lowest, the mean, median and modal scores for experimental group were 16, 5, 10.52, 10, 10 for those who participated in both pretest and posttest, and 13, 2, 10.05, 10, 9 for those who did only the posttest; and for the control were 15, 2, 9.72, 9,1310 for those who participated in both pretest and posttest, and 13, 4, 8.02, 7, 6 for those who did only the post-test. The Percentage number of participants that obtained particular scores on the post-test is presented in Table 9.

Table 9: Percentage of participants that obtained particular scores on the posttest

Score /19	Experimental group		Control	
	Given both pre-test and post-test	Given only post-test	Given both pre-test and post-test	Given only post-test
2	0.0	2.0	1.6	0.0
3	0.0	6.1	1.6	0.0
4	0.0	9.1	3.1	2.5
5	0.9	7.1	3.1	9.9
6	1.8	4.0	5.4	21.0
7	7.3	12.1	12.4	17.3
8	10.0	11.1	8.5	12.3
9	13.6	11.1	15.5	14.8
10	18.2	12.1	5.4	3.7
11	10.0	12.1	5.4	2.5
12	15.5	12.1	9.3	8.6
13	15.5	1.0	20.9	7.4
14	5.5	0.0	4.7	0.0
15	0.9	0.0	3.1	0.0
16	0.9	0.0	0.0	0.0

From Table 10, the average difficulty index on the pre-test was 0.19 and on the post-test was 0.51. It is observed that the pre-test was very difficult for the participants (I=0.19) while after applying the intervention (PBL), the participants performed fair on the post-test (I=0.51). In the post-test, the most difficulty items (I<0.5) were 3, 11, 13, 16, 16, 18 and 19.

Table 10: Percentage number of students giving a particular response and the difficulty index per item (correct responses are bolded)

Item	A		B		C		D		E		Difficulty index (I)	
	Pretest	posttest	pretest	posttest	pretest	posttest	pretest	posttest	pretest	posttest	pretest	posttest
1	39.3	17.2	23	13.6	11.3	56.6	26.4	12.6			0.11	0.57
2	29.7	60.4	26.4	15.3	43.9	24.3					0.30	0.60
3	10.5	46.1	18.8	14.3	26.8	14.3	23.8	15.3	20.1	10	0.11	0.46
4	9.2	8.6	25.9	57.8	23.0	14.6	21.8	10.7	20.1	8.4	0.26	0.58
5	20.5	11.2	23.4	10.7	17.2	13.1	18.0	54.2	20.9	10.7	0.18	0.54
6	13.6	14.6	6.9	50.8	17.9	19.6	18.6	15.0			0.69	0.51
7	28.9	13.8	30.5	19.8	28.5	14.6	12.1	51.8			0.12	0.52
8	18.4	11.0	28.0	13.8	15.1	8.6	15.5	53.2	23.0	13.4	0.16	0.53
9	18.8	11.9	37.7	16.9	13.4	51.8	10.9	8.4	19.2	11.0	0.13	0.52
10	34.7	16.5	26.4	13.4	17.6	53.7	21.3	16.5			0.18	0.54
11	20.1	12.9	30.5	16.9	11.3	47.3	38.1	22.9			0.11	0.47
12	27.2	15.5	23.8	50.8	31.0	21.2	18.0	12.4			0.24	0.51
13	27.2	20.0	18.4	47.3	23.0	14.6	31.4	18.1			0.18	0.47
14	18.0	15.0	18.8	13.8	36.4	50.8	26.8	20.3			0.36	0.51
15	23.4	14.1	40.2	28.6	13.8	42.0.0	22.6	15.3			0.14	0.42
16	18.8	46.1	22.2	17.7	27.6	16.9	31.4	19.3			0.19	0.46
17	22.6	11.7	18.8	54.9	36.8	18.4	21.8	15.0			0.19	0.55
18	27.6	17.7	23.0	15.0	36	18.1	13.4	49.2			0.13	0.49
19	18.4	12.9	32.2	16.5	35.1	23.4	14.2	47.3			0.14	0.47
Average											0.19	0.51

Discussion of Results

The major aim of PBL is to enable students to independently think and solve real life problems. This study thus aimed at analysing the effect of Problem-Based Learning instruction (PBL) instruction on secondary school physics students' understanding of electromagnetic waves. Thjis was investigated based on two research questions: 1) Is there a difference in the change in scores on the electromagnetic wave conceptual survey between physics students instructed using Problem-Based Learning and those instructed using traditional methods? 2) What are the students' difficulties with electromagnetic waves?

Addressing question 1: the findings in Tables 5 and 6 show that there was a statistical significant change in physics students' scores on the electromagnetic waves survey before and after instruction. The findings further show that change in scores among participants in the experimental and control groups was also statistically different as the mean scores and the standard deviations in the posttest were significantly different with better performance realized among the experimental (those instructed using PBL) than in the control (those instructed using traditional methods) group since the p value was less than 0.05 and the mean score for the experimental group was higher than that of the control group. The difference in scores between those exposed to both pretest and posttest and those exposed to only posttest was also statistically significant (Tables 7 and 8).

These findings of this study agree with those of Bilgin, Şenocak and Sözbilir (2009) who found out that there was a statistically significant difference between the conceptual success rates of pre-service teachers after being instructed under PBL. More to that, applying Problem-Based Learning instruction as observed by Gallardo Pérez et al. (2020) leads to better educational yields than traditional teaching and allows students to integrate the knowledge into their own to be able to solve existing problems. Allchin (2013) concluded that PBL generally impacts more positively on students' understanding of the nature of waves more than the conventional methods. Relating to findings about participants who had be exposed to pretest tending to score more on the posttest than those exposed to only posttest, Tongchai et al. (2011) noted that students' understanding depends directly on their previous level of engagement with a particular concept.

Considering question 2: from Table 10 basing on the column for difficulty index on the post-test, it is observed that generally, students find electromagnetic wave concepts difficulty ($I<0.8$ for all items). For example, in item 3, most students were not aware that electromagnetic waves have no mass, instead they were giving alternatives such as they have no wavelength/energy/frequency/velocity. In high school classes, teachers are expected to proclaim to learners that all electromagnetic waves are massless. In item 11, they could hardly differentiate between infra-red and ultra-violet radiation based on wavelength, instead, they were referring to other properties such as Color/Speed in vacuum. For item 13, many students showed lack of knowledge of heat rays being also referred to as infrared radiations. They were mistaking them to be either gamma rays or radio waves. Referring to item 15, students could hardly identify the range of frequencies our eyes are sensitive. Answering of this question seemed to be based on guess work. In items 16 and 19, students had difficulty aligning electromagnetic waves in order of either increasing frequency or wavelength. In item 18, they could not easily identify the electromagnetic waves that can be seen as visible light.

From these findings, it was observed that generally students have misconceptions and difficulties regarding electromagnetic waves. The low scores obtained as in this study by students may be related to the fact that the content of electromagnetic waves had just been covered hence students had not yet conceptualized it as pointed out by Tabor-Morris et al., (2017). However, Mioković, Varvodić and Radolić (2012) pointed out that students at all levels tend to have low conceptual understanding of wave the phenomena. Unver and Ozkarabacak (2018) in their study showed that participants generally confuse electromagnetic waves with sound waves, signal, power of attraction, and frequency concepts.

Conclusions

Instruction of waves relies heavily on the method of instruction used. Based on the study findings, it can be concluded that PBL is an effective method for instruction of electromagnetic waves since it significantly increases students' scores more compared to traditional methods. More to that, prior exposure of students to concepts using pre-test increases their conceptual understanding as observed in the findings. However, students generally face difficulties in dealing with and interpreting electromagnetic wave concepts. Therefore, the null hypotheses that there is no statistical significant difference between scores of experimental and control groups before and after instruction; and that there is no statistical evidence of students' difficulties with electromagnetic wave concepts were both rejected

Recommendations

From the findings of our study, we suggest that: teachers should put emphasis on major terms in waves such as 'frequency', 'wavelength', 'increasing', 'decreasing' so that students can be able to understand and differentiate them.

students be frequently presented with problems to keep them active.

School management should endeavour to support teachers and students under PBL with internet connected computers to help them easily research on complex concepts.

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