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Data Driven Insights into Problem -Based Learning: A Discriminant Analysis on Key Learner Variables

Dr. Amandeep Kaur
Assistant Professor, Khalsa College of Education, Amritsar

Abstract

The current study examines the effectiveness of problem-based learning for a select variable related to learning. This study identifies the average distance between control groups and experimental groups based on several dimensions (or variables) that are not necessarily independent, and the main dimensions that create the distance between experimental groups and experimental groups. We also examined whether the gap between the groups was statistically significant. The study was experimental in nature and research design of the pre-and post-test control group research was employed. For this purpose, a sample of 486 students were obtained by using matching with random assignment techniques. Seven variables- gender, intelligence, self-efficacy, self-regulatory, achievement, meta-cognitive knowledge and meta-cognitive regulation – have been taken into account. The obtained data were analyzed with discriminant analysis of winning scores. The findings of the study indicate that achievement in economics is one of the most important variables contributing significantly to the differences between experimental and control groups and self-regulated learning contributes the least to the differences between the two groups (experimental groups and control groups).

Keywords: Problem-based learning, metacognition, achievement, self-efficacy, self-regulation, discriminant analysis

Introduction

A systematic and efficient educational system is based on an effective teaching learning system. The writings of psychologists over hundred years have revealed that learning is not a simple matter. It is a highly complex process involving some identifiable operations and characteristics. Learning is a process of bringing relative changes in the behavior of learners through formal and informal experiences. It results in the acquisition of knowledge, skills, interests, attitude, etc. regarding one or the other things related to one's environment, the field of study, and specializations. The constructivist or modern approach to learning involves more interactive, student-based teaching and the students learn through group participation (Sunal et al, 1994). Student-centered learning strategies facilitate the development of higher-order thinking skills. Changed circumstances and increased expectations have led to the idea that now, the teachers need not only to be knowledge brokers but also learning counselors. Teachers must provide a wide range of learning experiences that encourage students to reflect upon and inquire into their thinking based on the problems of real life. It will improve critical thinking, develop metacognitive skills, and motivate the students to participate in the teaching-learning process. In this context, Forsythe (2002) argued, "PBL fosters a deeper approach to learning, promotes more versatility, develops knowledge, retention and recall skills." Problem-based learning strategy allows students to work in groups and identify the level of knowledge required to solve real-life problems (Raine & Collett, 2003).

Tan (2003) described, "The PBL approach involves harnessing bits of intelligence from within individuals, from the group of people, and from the environment to solve problems that are meaningful, relevant, and contextualized." The focus of the PBL process is to enhance the thinking of students from psychological, pedagogical, and technological perspectives. Watson (2004) described, "PBL is an instructional method that challenges the students to learn through working cooperatively in groups to seek solutions to the real-world problems." PBL is a powerful and engaging learning approach that leads to sustained and transferable learning (Jones et al., 1996 & Stepien et al., 1993). Norman and Schmidt (1992) argued, "PBL is most well-known for its use of problems as the starting point of learning."

The PBL process embraces the use of metacognition and self-regulation in the teaching-learning process. Weissinger (2004) asserted, "In a PBL environment, students regularly engage in metacognition. When discussing a problem, students think aloud, and share their thoughts via description and/ or visual representation". The facilitator in PBL asks metacognitive questions to encourage reflective thinking and encourages students to explain why they need specific information about the problem and why they consider a particular solution to be relevant to the problem (Hmelo-Silver & Evensen, 2000).

Research Objectives

1. To measure the mean distance between control and experimental groups based on several dimensions (or, variables), not necessarily independent;
2. To identify the main dimensions responsible for creating the gap between the experimental and control groups.
3. To test whether the gap between groups is statistically significant or not.

Methodology Adopted

The present investigation was experimental as it intended to study the effectiveness of the Web-based problem-based learning approach. A pre-test and post-test control group research design was employed. An experiment was conducted for three months. The present study was conducted on 486 students of XI grade studying in secondary schools of Amritsar District, Punjab (India). A purposive random sampling technique was used to select the sample for the present investigation.

A self-constructed achievement test in economics was used to measure the learning outcomes of students at the Pretest stage and Posttest stage of experimentation. The achievement test consisted of 60 objective test items (MCQ and fill-ups). The reliability of the achievement test was established by using the test-retest (stability) and split-half (Internal consistency) methods which came out to be 0.91 and 0.83 respectively. The face and content validity of the achievement test was established by the investigator.

The Metacognitive Awareness Inventory developed by (Schraw & Dennison, 1994) has been used for the present study. The inventory consists of 52 test items and it is categorized into two domains of cognition i.e., Metacognitive knowledge (Knowledge of cognition) and Metacognitive regulation (Regulation of cognition). The knowledge of cognition domain consists of 17 test items related to three sub-components: declarative knowledge, Procedural knowledge, and Conditional knowledge. Regulation of cognition consists of 34 test items and it is further categorized into five sub-processes, Planning, Information management strategies, Comprehension monitoring, Debugging strategies, and Evaluation.

A standardized Self-Efficacy Scale (2012) constructed by Dr. (Mrs.) G.P. Mathur and Dr. (Mrs.) Raj Kumari Bhatnagar has been used to measure the self-efficacy of secondary school students. There are 22 test items on the scale (15 positive items and 07 negative items). Test items are based on a Likert 5-point scale and each item has five alternatives. The items are related to eight factors viz. self-regulatory skills, Self-influence, Self-confidence, Social achievement, Self-evaluation, Self-esteem, Self-cognition.

A standardized Self-regulated learning scale constructed by Prof. Madhu Gupta and Ms. Dimple Mehtani (2008) has been employed. Test items are based on a Likert 5-point scale and each item has five alternatives: Strongly Agree, Agree, Undecided, Disagree, and Strongly

Disagree. There are 48 test items in the scale dealing with six dimensions of self-regulated learning: Self-awareness, Planning, and Goal setting, Self-motivation, Self-control, Self-evaluation, and Self-modification.

Analysis and Interpretation of Data

To analyze the obtained data, linear discriminant analysis was employed. The description of the analysis is given below:

Discriminant Analysis

The data has been analyzed by applying Discriminant analysis to attain the objectives of the present study. Discriminant analysis is a multivariate technique used to assign observations to previously defined groups; the grouping variable is usually categorical. One of the main objectives of discriminant analysis is to identify the combination of each variable in separating the groups. Discriminant analysis is employed to predict the group membership from a set of independent variables. It explains the testing of variables and how poorly or well the units of observations are classified. More specifically, Discriminant analysis describes how groups are statistically differentiated from each other.

For this purpose, Fisher's *linear discriminant analysis* duly coupled with the computation of *Mahalanobis generalized distance* (D^2) is applied. Janette Walde (2007) stated, "Mahalanobis D^2 is appropriate for the stepwise procedure which involves entering the independent variables into the discriminant function on at a time based on their discriminant power." The analysis is carried out in different stages, and the results have been presented accordingly, as follows:

Stages of Analysis

Stage 1: Linear Discriminant Function Analysis (Ldf)

Stage 2: Identification of the Major Dimensions of *Inter-Group* Gaps

Stage 3: Error of Misclassification

Stage 1: Linear Discriminant Function Analysis (Ldf)

Tharwart, Ibrahim, Hassanien, and Gaber (2017) stated, " The main goal of linear discriminant analysis is to project the original data matrix onto a lower dimensional space" para (5). LDA By considering all the *seven* dimensions [*viz.,* Gender (GNDR), Intelligence (INTL), Gain in achievement scores in economics (GNAC), Gain in metacognitive knowledge (GNMK), and Gain in metacognitive regulation (GNMR), Self-efficacy (SE), Self-regulation (SR)] the results obtained have been put in Table 1.

Table1

Results on the LDF Estimated from the Full Set of Data

S. No.	Variable	LDF Coefficient	Relative Importance (%)	Ranking
1	GNDR	0.1931	0.01	7
2	INTL	-0.0435	8.93	4
3	SEFF	0.0091	0.23	6
4	SREG	0.0054	0.71	5
5	GNAC	-0.3797	60.37	1
6	GNMK	-0.2820	16.07	2
7	GNMR	-0.1520	13.68	3

$D^2 = 3.127$; F for D^2 (at 7 & 478 d.f.) = 53.60^{***}; *p*-value for $F < 0.0001$

As per Table 1, the computed value of Mahalanobis-D^2 is 3.127, which is tested through F-test, and F-ratio for D^2 came out to 53.60 which is statistically highly significant at ($p < 0.0001$). This implies that there exists a highly significant gap between the two groups (experimental and control) as adjudged based on all the seven variables taken together. In this gap, the largest contribution (60.37%) is attributable to a gain in achievement scores whereas, on the other extreme, the smallest contribution (0.01%) is due to gender.

Stage 2: Identification of the Major Dimensions of Inter-Group Gaps

For this purpose, *Step-down* discriminant analysis is carried out. In such an analysis, the relative contribution of each of the variables in D^2 is estimated and the variable associated with the least contribution is identified. Then the analysis is re-carried out by leaving out this variable (least contributor variable). The new value of D^2 will be lower in magnitude compared to the previous value. Reduction in the observed value of D^2 is tested through F-test. If the reduction happened to be statistically significant (at a 5% probability level), the above-identified variable cannot be treated to be rejected and is, therefore, retained in the analysis. Otherwise, the variable is dropped out and the analysis is carried out iteratively unless & until the reduction in D^2 happens to be statistically significant.

The finally obtained curtailed list of the variables appearing in the discriminant analysis is accepted to constitute. The meaningful determinants are responsible for creating a significant divergence between the control and the experimental groups. Results from the iterative analysis have been put in Table 2.

Table 2

Successively Left-Out Set of Variables in Fisher's Linear Discriminant Analysis in Respect of Divergence Between Control and Experimental Groups

Iteration No.	Mahalanobis- D^2	Omitted Variable	%age Change in D^2	F-Value for Change in D^2	p-Value for the Change	Remark
1	3.127	-	-	-	-	-
2	3.118	GNDR	0.29	1.379	0.2409	NS
3	3.103	SEFF	0.48	2.309	0.1293	NS

4	3.074	SREG	0.93	4.495	0.0345	*

Note: ** Significant at 5% probability level; NS: Insignificant

Evidently, as per the analysis, we can afford to drop out two of the variables, *viz.* gender and self-efficacy, because by doing so, we will not lose significant information (in terms of the fall in D^2 value). Now, only five significant dimensions in respect of which the *final* results of discriminant analysis have been presented in Table 3.

Table 3

Optimum Results on the LDF Estimated from the Curtailed Set of Data

S. No.	Variable	LDF Coefficient	Relative Importance (%)	Ranking
1	INTL	-0.0435	8.99	4
2	SREG	0.0063	0.84	5
3	GNAC	-0.3768	60.37	1
4	GNMK	-0.2796	16.06	2
5	GNMR	-0.1515	13.74	3

$D^2 = 3.103$; F for D^2 (at 5 & 480 d.f.) = 74.78^{***}; p-value for F < 0.0001

As per Table 3, the mean gap between the two groups continues to remain highly significant at 0.1 level of significance ($D^2 = 3.103$; F for $D^2 = 74.78$, p-value < 0.0001). In this gap, the most significant variables (in the descending order of importance) are GNAC, GNMK, GNMR, INTL, and SREG, with their relative contributions (in the value of D^2) being 60.4, 16.1, 13.7, 9.0, and 0.8 percent, respectively.

As per the results obtained through Table 3, the estimated Fisher's linear discriminant function (LDF) can be written as

$$Z = -0.0435\ \text{INTL} + 0.0063\ \text{SREG} - 0.3768\ \text{GNAC} - 0.2796\ \text{GNMK} - 0.1515\ \text{GNMR} \quad \cdots (1)$$

Threshold value $k = -4.2907$

Owing to the statistical significance of the value of D^2 (= 3.103), it can be said that the estimated LDF is capable of making precise discrimination between the two groups of students.

Stage 3: Error of Misclassification

Finally, through the estimated LDF, the *error of misclassification* is also estimated to find out the extent of *overlap* between the two groups of students. For doing so, observed values for all the five (5) variables in respect of each of the 486 students are substituted, in turn, in LDF Equation (1), is evaluated. A student is then put into the control or the experimental group, according to the computed value of $Z \leq k$ or $Z > k$, where k (= – 4.2907) represents the estimated *threshold value*. As per the classification, Table 4 is obtained as follows:

Table 4

Classification of the Observations into the Two Groups

Group	Control	Experimental
Control	194	49
Experimental	37	206

Error of Misclassification = 17.69%

Thus, as per the classification 194 of the 243 observations of the control group can be rightly into this group, whereas 49 observations get misclassified into the experimental group. Similarly, out of the totality of 243 observations of the experimental group, 206 observations can be rightly classified into this very group, but 37 observations get misclassified into the control group. As a result, there occurs an error of misclassification of the observations to the tune of

17.7 percent. This implies that although there is a significant gap between the two groups, there exists a fair extent of overlap between the two groups of students.

Results and Discussion

From the above discussion, it has been summarized that achievement in economics is one of the most significant variables that contributed at large to the gap between the experimental and control groups and self-regulated learning makes the least contribution to the gap between both groups. It was also found that achievement in economics, metacognitive knowledge, metacognitive regulation, and self-regulation were meaningful determinants that were responsible for creating significant divergence between the control and the experimental group. Selcuk, Sahin, and Caliskan (2013) and Zahid, Varghese, Mohammad, and Ayed (2016) found significant improvement in performance of students of PBL group. Ramaden, Soliman, Mouty (2020) and Izzati (2021) divulged that teaching through PBL approach has more boosting effect on the achievement of students. The findings of Kuvac and Koc (2018) concluded that metacognitive awareness of participants of experimental group got enhanced when they were exposed to PBL group. Saputro et. al. (2020) and Izzati (2021) also confirmed that PBL had potential to affect and improve the metacognitive knowledge and regulation of students and PBL was found more effective especially with respect to regulation of cognition i.e., component of metacognition.

The present investigation also found that self-regulation of students accounted for difference in metacognitive awareness of the students when they were subjected to Problem-based learning approach. Sahyar and Sani (2017) observed that students who have above average self-regulated learning is better than the students who have below average self-regulated learning on different skills in a PBL environment

Educational Implications

The findings of the study suggested significant improvement in the metacognitive skills and achievement levels of the students due to the application of problem-based learning. This finding is useful for curriculum developers. They may suggest incorporating a problem based on the content at the beginning of the chapter. The results of the study demonstrated that students with low self-efficacy levels exhibited more improvement in metacognitive skills and achievement in economics and vice versa when they were exposed to problem-based learning. Problem-based learning proved more beneficial for students with low self-efficacy levels. Hence, teachers may arrange practice sessions and more challenging tasks for students with high self-efficacy levels and may encourage the students to use planning and information-processing strategies to develop metacognitive skills. Teachers may motivate students with low self-efficacy levels to maintain and sustain confidence in their abilities. The findings of the study also demonstrated that students with low self-efficacy exhibited more improvement in achievement in economics when they were treated through PBL. Hence, teachers may use various sources of self-efficacy (i.e., verbal persuasion and role modeling) to encourage students with different levels of self-efficacy and it also showed the effectiveness of PBL for students having low efficacy levels which further enhances the achievement of students.

The results of the study also demonstrated a significant distance between the two groups exposed to two different learning approaches (Problem-based learning and traditional learning approach) and achievement is the most significant variable that contributed most to the distance. This finding is quite significant for policymakers. Hence, it is recommended that policymakers suggest organizing faculty induction programs at the beginning of sessions for teachers of different subjects and different levels of education. It will enhance the abilities of the teachers to explore different approaches by which they will able to make their teaching-learning process activity-based and effective.

References

Forsythe, F. (2002). The role of problem-based learning and information technology in a spoon-fed undergraduate environment. In T. Johannessen, A. Pedersen, & K. Petersen (Eds), *Educational Innovation in Economics and Business* (Vol. 6, pp. 147-161). Kluwer Academic Publishers: Amsterdam.

Hmelo-Silver, C. E., & Evenson, D. H. (2000). Problem-based learning: Gaining insights on learning interactions through multiple methods of inquiry. In D. H. Evenson & C. E. Hmelo-Silver (Eds.), *Problem-based learning: A research perspective on learning interactions* (1st ed., pp. 1-12). Mahwah, NJ: Erlbaum.

Izzati, L. R. (2021). The effect of problem-based learning to improve students' metacognition skills in solving mathematical problems based on cognitive style. *Journal of Physics: Conference Series*, *1918*, 1-6. doi:10.1088/1742-6596/1918/4/042073

Jones, B. F., Rasmussen, C. M., & Moffitt, M. C. (1996). *Real-life problem solving: A collaborative approach to interdisciplinary learning*. Washington, DC: American Psychological Association.

Norman, G. R., & Schmidt, H. G. (1992). The psychological basis of problem-based learning: A review of the evidence. *Academic Medicine, 67*(9), 557-565. http://dx.doi.org/10.1097/00001888-199209000-00002

Raine, D., & Collett, J. (2003). Problem based learning in astrophysics. *European Journal of Physics, 24*(2), 1-10. doi:10.1088/0143-0807/24/2/306

Ramadan, H. A., Soliman, S. M., & Mouty, S. M. E. (2020). Problem Based Learning strategy verses lecture effect on academic achievement of Technical Health Nursing Students.

IOSR Journal of Nursing and Health Sciences, 9(4), 52-61. Retrieved from http://www.iosrjournals.org/

Selcuk, G. S., Caliskan, S., & Sahin, M. (2013). A comparison of achievement in problem-based, strategic and traditional learning classes in physics. *International Journal on New Trends in Education and Their Implications, 4*(1), 154-164. Retrieved from https://www.iconte.org/

Tan, O. S. (2003). *Problem-based learning innovation: Using problems to power learning in the 21st century*. Singapore: Thomson Learning.

Weinstein, C. E., & Mayer, R. E. (1986). The teaching of learning strategies. In M. C. Wittrock (Eds.), *Handbook of research on teaching* (3rd ed., pp. 315-327). New York: Macmillan.

Weissinger, P. A. (2004). Critical thinking, metacognition, and problem-based learning. In O. S. Tan (Eds.), *Enhancing thinking through problem-based learning approaches* (pp. 39-60). Singapore: Cengage Learning