ROBUST STATISTICAL TECHNIQUES FOR EDUCATIONAL EVALUATION IN UNIVERSITY TECHNICAL STUDIES: MEDIAN AND WILCOXON-MANN-WHITNEY (WMW) TEST

TÉCNICAS ESTADÍSTICAS ROBUSTAS PARA LA EVALUACIÓN EDUCATIVA EN ESTUDIOS TÉCNICOS UNIVERSITARIOS: TESTS DE LA MEDIANA Y DE WILCOXON-MANN-WHITNEY (WMW)

Raúl Montes Pajuelo [1*], Ángel Mariano Rodríguez Pérez [2], Julio José Caparros Mancera [3], Cesar Antonio Rodríguez González [4]

[1,3,4] *University of Huelva, Spain*
[2] *University of Almería, Spain*

[*] *raul.montes@dci.uhu.es*

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HIGHLIGHTS

- In engineering and architecture education, PBL (Problem Based Learning) has been evaluated to see if it is effective.
- Two robust statistical tests were used: the median test and the Wilcoxon-Mann-Whitney (WMW) test.
- It is shown that there is a significant difference in learning using PBL compared to traditional methods.

RESUMEN

El aprendizaje basado en problemas (ABP) es un método de enseñanza que se utiliza cada vez más en la enseñanza técnica. Tanto en la enseñanza de la ingeniería como en la de la arquitectura, el ABP se ha evaluado y ha demostrado su eficacia para mejorar el rendimiento académico de los estudiantes. La necesidad de trabajar en grupo y la limitación del número de alumnos por sesión de ABP requieren el uso de técnicas estadísticas robustas en la evaluación estadística correspondiente. En el presente trabajo se aplicaron dos pruebas estadísticas robustas: la prueba de la mediana y la prueba de Wilcoxon-Mann-Whitney (WMW). Utilizando una muestra de 35 estudiantes del Máster en Ingeniería Industrial de la Universidad de Huelva, distribuidos en tres cursos académicos (2021-22, 2022-23 y 2023-24), se aplicaron dichas pruebas en relación con el rendimiento académico. Hubo un grupo experimental (19 alumnos) y un grupo control (16 alumnos). Se han aclarado los detalles de la aplicación de cada prueba, incluyendo las hipótesis nula y alternativa, los estadísticos respectivos de cada prueba, y se ha resuelto el caso utilizando R. Se demuestra que existe una diferencia significativa en el aprendizaje entre el grupo experimental y el grupo de control, basándose en las pruebas de la mediana y de Wilcoxon-Mann-Whitney (WMW).

Palabras clave: *Técnicas estadísticas sólidas, metodologías didácticas activas, aprendizaje basado en problemas, aprendizaje basado en proyectos.*

ABSTRACT

Problem Based Learning (PBL) is a teaching method that is increasingly being used in technical education. In both engineering and architecture education, PBL has been evaluated and shown to be effective in improving students' academic performance. The need to work in groups and the limitation of the number of students per PBL session require the use of robust statistical techniques in the corresponding statistical evaluation. In the present work, two robust statistical tests were applied: the median test and the Wilcoxon-Mann-Whitney (WMW) test. Using a sample of 35 students of the Master in Industrial Engineering at the University of Huelva, distributed over three academic years (2021-22, 2022-23 and 2023-24), the said tests were applied in relation to academic performance. There was an experimental group (19 students) and a control group (16 students). The details of the application of each test have been clarified, including the null and alternative hypotheses, the respective statistics of each test, and the case has been solved using R. It is shown that there is a significant difference in learning between the experimental group and the control group, based on median and Wilcoxon-Mann-Whitney (WMW) tests.

Keywords: *Robust statistical techniques, active didactic methodologies, problem -based learning, project -based learning.*

1. INTRODUCTION

In technical education, including both engineering and architecture, active teaching methods are often used. Among these methodologies, problem-based learning (PBL) and project-based learning stand out, although there are many variants and also other different active teaching methodologies [1-3]. However, a common feature of these active methods is that, due to the requirements of their implementation, the number of students participating in each session rarely exceeds 50. And even more frequently, in PBL, it is common for there to be no more than 10 or 20 students per session, grouped again by the requirements of the methodology itself in the working sub-groups specific to this teaching methodology, often from 3 to 6 students [4]. On the other hand, the need to evaluate teaching methods, whether active or traditional, such as the expository method, is becoming more frequent [5, 6]. While the number of students in an expository method is mainly limited by operational and infrastructural issues - it is common to have more than 100 students per session, although its convenience is debatable - in the case of active methodologies it is limited by the implementation of the methodology itself. Educational evaluation, e.g. to test for differences in academic performance between groups of learners and/or methods, can use descriptive statistics in its statistical techniques for samples of more than 50 learners, e.g. a Student's t-test. However, these statistical techniques cannot be used with the small groups typical of active methods, as sample normality cannot be guaranteed. Therefore, robust statistical techniques are often used [7-9]. However, the use of these robust statistical techniques has a number of prescriptions and procedures that have been analysed in this paper. Specifically, two robust statistical tests have been applied in this paper: the median test [10] and the Wilcoxon-Mann-Whitney (WMW) test [11]. Using a sample of 35 students of the Master's Degree in Industrial Engineering at the University of Huelva, spread over three academic years (2021-22, 2022-23 and 2023-24), the aforementioned tests were applied in relation to academic performance. There was an experimental group (19 students) and a control group (16 students). The details of the application of each test have been clarified, including the null and alternative hypotheses, the respective statistics of each test, and the case has been solved using R. It is shown that there is a significant difference in learning between the experimental group and the control group, based on median and Wilcoxon-Mann-Whitney (WMW) tests.

2. MATERIALS AND METHODS

2.1 Theoretical foundations of problem-based learning in technical education

Problem Based Learning (hereinafter PBL) is a specific didactic approach in which the teaching and learning process is characterised by the fact that students are confronted with more or less complex problems, usually real ones, for which they can use whatever materials they consider necessary. Although the origins of PBL lie in law and Anglo-Saxon jurisprudence and not in medicine, as is commonly believed [12, 13], authors on the subject date its first application in the scientific field to the proposal of the McMaster University School of Medicine (Canada) between the 1960s and 1970s [14]. Since then, PBL has evolved and adapted to the needs of the different fields in which it has been applied, including engineering and architecture. This has meant that there have been many variations on the original proposal. However, its essential elements, derived from the model developed at McMaster [15-20], have been retained. The application of PBL in engineering education has previous works based on the suitability of this teaching methodology for solving specific problems in different specialities: electrical, civil, mechanical, etc. [21-29]. As for the application of PBL in the teaching of architecture, it requires appropriate adaptation by specialists in its teaching, given the high weight acquired by the architectural project and where there are related methodologies, but with different nuances [2]. The following bases for the application of PBL in engineering have taken into account the data and experiences collected during different academic years, from 2013-14 to the academic year 2022-23, in different degrees and subjects belonging to the area of Civil Engineering at the University of Huelva. Since the academic year 2013-14, a PBL has been implemented in the subjects of the area.

The theoretical bases of PBL in technical education can be summarised in the following points [30]:

- Problem Based Learning (PBL) as a specific teaching method. PBL applied to engineering education is a specific didactic in which the teaching and learning process is characterised by the confrontation of students with more or less complex problems, most of them real, for which they have as much material at their disposal as they consider necessary. There is collaborative work and autonomous work, which are not mutually exclusive and which are integrated into or accompany PBL.
- Student-centred learning. Students must take responsibility for their own learning, guided by a teacher who assumes the role of tutor and becomes a consultant to the student, identifying the elements necessary to better understand and manage the problem they are working on.
- Generating learning in sub-groups. In science, according to some authors, working groups are formed with 5 to 8 students; specifically in engineering and architecture, we recommend 3 to 4 students per group (5 in exceptional cases). The teacher plays the role of tutor and manager, facilitating the work of forming these sub-groups.
- The teacher takes on the role of a tutor. The teacher in the context of PBL is called a facilitator or tutor. The role of the tutor is first of all to observe and record the work of the sub-groups. After establishing the case and its milestones for solution, he/she should ask the students specific questions to help them think and find the best way to understand and solve the problem.
- Learning lies in the creation of problems. In PBL for engineering and architecture, students are given a case study with basic materials, including text and graphic documentation. Drawings of structures, construction details, hydraulic installations, etc. are often attractive because students feel close to their engineering vocation. Curiosity becomes an active force to be managed by the tutor to initiate the case study. The proposed case represents the challenge that the students will face in practice and provides relevance and motivation for learning.
- Problem solving develops competences. For technical disciplines, it is necessary to present a problem from the real world, or as close as possible to a real situation, related to applications in the professional context in which the student will work in the future. The problems underlying the case are applied to each technical discipline.
- Self-directed learning creates new knowledge. Finally, students are expected to learn from real-world knowledge and the accumulation of experience through their own study and research. The information provided by previous experience of other authors is essential in technical disciplines where previous experience carries considerable weight. During this self-directed learning, students have worked together, discussed, compared, analysed, revised and constantly debated what they have studied and learned. The mere accumulation of more or less unrelated knowledge does not result in an integrated body of knowledge.

2.2 Description of the quasi-experimental model used

A quasi-experimental model was used to evaluate PBL. The effect of the PBL treatment on academic performance was measured in experimental groups and compared with groups that did not receive the treatment. The control groups, which did not receive PBL, received a traditional expository method (TEM) with problems set by the teacher throughout the semester. The model was of the quasi-experimental type, as it was not possible to ensure a completely random assignment of students to the control (CG) or experimental (EG) groups. The objective knowledge control tests provided academic performance through the marking of the tests. They were carefully designed to meet the objectives set. The final approval of each test includes an assessment of the balance in the difficulty of the tests for the different groups and a check of the triangulation in the correction of the tests.

The research required a teaching programme for the subjects and an ad hoc organisation of the groups, which makes the method quasi-experimental, as we have already mentioned. Both the TEM expository method and the PBL were continuously assessed with tutorial exercises throughout the four-month period, with the support of the virtual platform. All groups were provided with the necessary written material to cover the syllabus. Figure 1 shows the procedure followed.

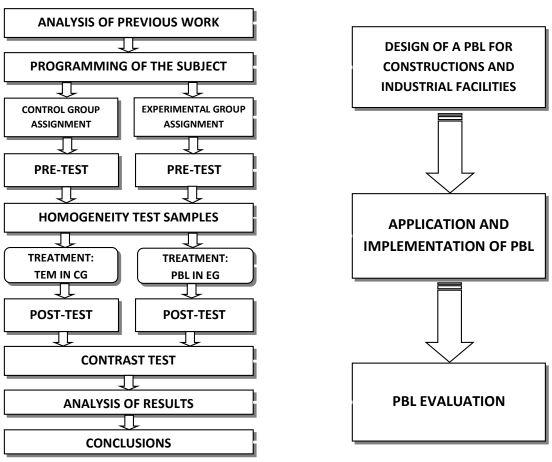

***Fig. 1:** Quasi-experimental method for the evaluation of a PBL. (Source: self made)*

2.3 Description of the non-parametric statistical tests used: median test and Wilcoxon-Mann-Whitney (WMW) test

Educational evaluation, e.g., to test for differences in academic performance between groups of students and/or methods, can use descriptive statistics in its statistical techniques for samples of more than 50 students, e.g., a Student's t-test. However, these statistical techniques cannot be used with the small groups typical of active methods because sample normality cannot be guaranteed. Therefore, robust statistical methods are often used. However, the use of these robust statistical techniques has several prescriptions and procedures that have been analysed in this paper.

Two robust statistical tests have been applied: the median test and the Wilcoxon-Mann-Whitney (WMW) test. Using a sample of 37 students, spread over three academic years (2021-22, 2022-23 and 2023-24), the above tests were applied to academic performance. There was an experimental group (18 students) and a control group (19 students).

The students belong to the master's degree in Industrial Engineering.

The subject to which PBL was applied is 'Industrial Constructions and Facilities'.

2.3.1 Median or chi-square test

Let be $X_1, \ldots, X_m, Y_1, \ldots, Y_n$ samples from two populations and M_s the median of the combined sample. Then, the contrast statistic is

$$\lambda = \frac{(m+n)(an-bm)^2}{mn(a+b)(m+n-a-b)},$$

where a and b are the number of individuals in the first and second sample, respectively, whose magnitude does not exceed M_s. Fixed α level of significance,

- If $\lambda < \chi_{1;\alpha}$, the medians of the two populations are accepted to be equal (and the populations may be compared).
- If $\lambda \geq \chi_{1;\alpha}$, the medians of the two populations are rejected to be equal (and the populations may not be compared).

2.3.2 Wilcoxon-Mann-Whitney (WMW) test

Let be $X_1, \ldots, X_m, Y_1, \ldots, Y_n$ samples from two populations and

$$D_{ij} = \begin{cases} 1 & Y_j < X_i \\ 0 & Y_j \geq X_i \end{cases},$$

then, the contrast statistic is

$$W = \sum_{i=1}^{m} \sum_{j=1}^{n} D_{ij} \,.$$

Fixed α level of significance,

- If $mn - w_{m,n;\alpha/2} < W < w_{m,n;\alpha/2}$, the medians of the two populations are accepted to be equal (populations comparable),
- If $W \leq mn - w_{m,n;\alpha/2}$ or $w_{m,n;\alpha/2} \leq W$, the medians of the two populations are rejected to be equal (populations not comparable),

where $w_{m,n;\alpha/2}$ is the smallest integer that verifies

$P\{W \geq w_{m,n;\alpha/2}\} \leq \alpha/2.$

3. RESULTS AND DISCUSSION

3.1 Results of academic performance tests

Using a sample of 35 students from the master's degree in Industrial Engineering at the University of Huelva, divided into three academic years (2021-22, 2022-23 and 2023-24), the aforementioned tests have been applied, with respect to academic performance. There was an experimental group (of 19 students) and a control group (of 16 students). The application details of each test have been clarified, including the null and alternative hypotheses, the respective statistics of each test, and using R software [31] the case has been resolved. It is shown that there is a significant difference in the learning of the experimental group with respect to the control group, based on median [32] and Wilcoxon-Mann-Whitney (WMW) [33] tests.

***Table 1**: Sample results of academic performance.*

CONTROL GROUP (PRE-TEST)	EXPERIMENTAL GROUP (PRE-TEST)	CONTROL GROUP (POST-TEST)	EXPERIMENTAL GROUP (POST-TEST)
1,5	1,0	2,0	3,0
2,0	2,3	2,0	3,3
2,3	2,3	2,3	3,7
2,5	2,5	2,6	4,0
2,8	2,6	2,7	4,4
3,0	2,7	2,8	5,0
3,2	2,8	3,0	5,5
3,3	2,9	3,0	6,0
3,5	3,0	3,3	6,5
3,5	3,0	3,0	7,0
3,7	3,3	3,5	7,0
3,9	3,5	3,7	7,6
4,0	3,7	4,0	8,0
4,2	4,0	4,0	8,0
4,3	4,0	5,0	8,3
4,4	4,4	5,5	8,5
4,5	4,0	6,6	8,7
4,5	4,5	6,8	9,0
4,5	5,0	7,0	
5,0	7,0		
5,0	8,0		
5,3	8,0		
5,5			
5,6			

Source: Own data.
Note: Ordered according to the median test.

3.2 Null and alternative hypotheses for the homogeneity of samples study (median test)

It is carried out on the results of the pre-test, to check whether the samples are comparable. The test is defined by:

1) Quasi-experimental design, two independent groups, with one independent variable and small samples (n < 30).
2) Ordinal level of measurement.
3) Bilateral hypothesis:
   H0: There are no differences between the two groups.
   H1: There are significant differences.
4) Non-parametric test. Median test, since the measure used refers to only two ranges or categories: above or below the median or central place of all the scores.

Steps:
Obtaining M_s=3.7 and the values a=11, b=13 (defined on section 2.3.1).
Carry out the test explained in section 2.3.1.
We have used the R software to carry out the tests. R returns the p-value, i.e., the minimum value of α the for which the null hypothesis is rejected. In this case, λ=0.80851, and the p-value is 0.3686. We use a level of significance α=0.05, so the null hypothesis (H0) is therefore accepted. the samples of the experimental and control groups are comparable. With an approach homologous to that followed for the pre-test, for the case of the post-test with the formulation of the median test, it turns out that: As λ=7.7954 and the p-value is 0.005232, there are significant differences between the two groups, at the post-test level and for a confidence level of 95%. The null hypothesis (H0) is therefore rejected and the alternative hypothesis (H1) is accepted. there are significant differences in academic performance when receiving PBL versus receiving another traditional method.

3.3 Null and alternative hypotheses for Wilcoxon-Mann-Whitney test

It is carried out on the results of the pre-test, to check whether the samples are comparable. The test is defined by:

1) Quasi-experimental design, two independent groups, with one independent variable and small samples (n < 30).
2) Ordinal level of measurement.
3) Bilateral hypothesis:
   H0: There are no differences between the two groups.
   H1: There are significant differences.
4) Non-parametric test.

Steps:
Obtaining D_{ij} (defined on section 2.3.2).
Carry out the test explained in section 2.3.2 (used R software).
In this case, W =295, and the p-value is 0.506. With a level of significance α=0.05, the null hypothesis (H0) is therefore accepted. the samples of the experimental and control groups are comparable. With an approach homologous to that followed for the pre-test, for the case of the post-test with the formulation of the WMW test, it turns out that: As W=51 and the p-value is 0.00013, there are significant differences between the two groups, at the post-test level and for a confidence level of 95%. The null hypothesis (H0) is therefore rejected and the alternative hypothesis (H1) is accepted. There are significant differences in academic performance when receiving PBL versus receiving another traditional method.

4. CONCLUSIONS

It is shown that there is a significant difference in learning between the experimental group and the control group, based on the median and Wilcoxon-Mann-Whitney (WMW) test. There are significant differences in construction learning between students who have participated in a PBL-based teaching programme and other students who have participated in a learning programme following a combined traditional expository and teacher-led problem-solving method. It follows, therefore, that the PBL is effective with a period of 8 weeks of application, thus also fulfilling the main objective of the research.

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