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Implementation of Completely Randomized Design (CRD) using R Software to Evaluate Linear Algebra Learning Systems Pasca the Covid-19 Pandemic

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ABSTRACT

Completely Randomized Design (CRD) is an experimental design that is applied based on treatment control by researchers. In this study, CRD was applied to evaluate the learning system of the Linear Algebra course pasca the Covid-19 pandemic using R Software. The experiment was carried out as many as 2 tests which were categorized as learning group 1 consisting of 28 students and learning group 2 consisting of 29 students. The treatment given is based on the learning system before the Covid-19 pandemic which was carried out face-to-face, during the pandemic which was carried out online and pasca the pandemic which was carried out in a mixed manner (face-to-face and online). The online learning system during the pandemic provides better student learning outcomes than face-to-face or through a blended learning system. However, this must be further evaluated for environmental conditions and learning models so that they can be applied to the learning system pasca the Covid-19 pandemic.

Keywords: *CRD, Learning System, Linear Algebra, R Software*.

Introduction

Education is one way for individuals to get a quality of life that is able to compete in every changing era. The condition of education in the recent period has changed significantly due to the outbreak of the Covid-19 pandemic. This situation causes the entire order of the educational process, especially the learning process, to decrease. This happened due to the impact of the emergence of the Covid-19 pandemic outbreak which required the cessation of all activities. Before the outbreak of the Covid-19 pandemic, the learning process took place as usual. However, learning activities were stopped due to the government's appeal to reduce the spread of Covid-19. For approximately 2 years starting from 2020-2022 the pandemic has continued, requiring the government to set a strategy so that all activities can continue to be carried out, including the learning process in the field of education [1].

One of the strategies implemented by the government during the pandemic is to implement an online learning process. The effect of this application causes students and teaching staff to carry out the teaching and learning process from home. This activity is also called Work from Home (WFH). The WFH process experienced obstacles, namely the material was not delivered properly and the lack of adequate network facilities in some areas [2]. However, this also requires teaching staff to be able to improve competence and have a way to handle every obstacle that occurs during the teaching and learning process. WFH learning activities have been carried out and prove that learning activities in the field of education can take place during pandemic [3];[4];[5], [6].

After successfully going through learning activities during the pandemic, the government made changes back to the education system. This is an impact after the pandemic has decreased and almost in several regions in Indonesia there are no more victims infected with Covid-19. As a result, some of the learning process takes place divided into two parts, namely the face-to-face system directly and online. This situation causes policy differences in each educational institution.

Generally, face-to-face learning is more effective than online [7][8][9][10]. However, it does not rule out the possibility that learning carried out by applying these 2 methods provides better results [11]. This refers

to teaching staff and students who have become accustomed to learning situations during the pandemic [12][13].

Based on the type of learning that took place before the pandemic, during the pandemic and after the pandemic, it is necessary to test to be able to see which types of learning tend to be more effective to apply to post-pandemic conditions. The test was carried out by applying an experimental design using Completely Randomized Design (CRD) [14][15]. The results of the CRD experiment will be known whether or not there is an influence of the face-to-face, online or both learning processes (face-to-face and online) on student learning outcomes. The experiment was carried out on the Linear Algebra learning process with 2 repetitions from 2 groups of students formed. Several studies that have applied CRD in looking at learning effectiveness, such as [16] prove that the Team Games Tournament (TGT) learning method and the Role Playing learning method are significantly different from applying CRD experimental techniques. Furthermore, [17] gave results in their research that the existence of a learning system by applying Augmented reality is more effective than learning carried out using modules and worksheets. Based on the research that has been done, this study conducted a CRD experimental to determine the effectiveness of the learning system Linear Algebra pasca the Covid-19 pandemic using R Software.

Research Methods

Literature Review

1) Completely Randomized Design (CRD)

Experiments were conducted as a means of obtaining information about the true condition of the population. Information that can be generated from an experiment includes testing population parameters, making decisions after testing and planning further research. Experimental designs are made to obtain as much information as possible with relatively minimum cost, effort and time. Some types of experimental designs include, Completely Randomized Design (CRD), Completely Randomized Block Design (CRBD), Latin Square Design, etc. [18][19]. The selection of the type of experimental design is based on the consideration of the researcher. The selection of CRD is typically based on the simplicity, randomization, and homogeneity of experimental units. It is a practical choice for researchers with limited resources or when the experimental environment is stable and homogeneous. However, when there are known sources of variability among the experimental units, researchers may consider more complex designs to account for this variability. CRD remains an essential tool for many types of experiments, especially those in the initial stages or with straightforward requirements. This study will apply the CRD type of experiment to see the effectiveness of learning pasca the Covid-19 pandemic.

The primary statistical tool used for analyzing the data from a CRD experiment is Analysis of Variance (ANOVA). ANOVA allows the researcher to determine whether the differences in the means of the treatment groups are statistically significant. If the analysis shows significant differences between groups, it can be concluded that the treatments had an effect. If no significant differences are found, the treatments are likely to have produced similar outcomes.

CRD is an experimental design that is observed once in each experimental unit with homogeneous conditions and given the i-th treatment. In CRD experiments, research must be conducted by paying attention to the source of diversity that causes the experimental unit to be inhomogeneous in order to maintain homogeneity conditions in the experimental unit. The CRD linear model can be mathematically written as follows:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{j(i)};\ i = 1,2,\dots,t;\ j = 1,2,\dots,r_i \quad (1)$$

where Y_{ij} is the j-th observation in the i-th treatment, μ is the total mean, τ_i is the effect of the i-th treatment and the $\varepsilon_{j(i)}$ is the deviation of the observation (ij) from the treatment mean or also known as experimental error. Some assumptions in CRD that must be met include the following:

1. μ is same for every treatment.
2. $\varepsilon_{j(i)} \sim N(0, \sigma_\varepsilon^2)$

In CRD there is a diversity analysis, in this case it can be done using the ANOVA (Analysis of Variance) table presented in Table 1.

Table 1. Analysis of Variance (ANOVA)

Variance Source	Degree of Freedom (df)	Sum of Squares (SS)	Middle Squares (MS)
Treatment	$t-1$	SST	MST
Error	$n-t$	SSE	MSE
Total	$n-1$	SSTo	

This are the formula to calculate the sum of squares and middle squares:

$$SST = \sum_{i=1}^{t}\sum_{j=1}^{r_i}(\bar{Y}_{i.} - \bar{Y}_{..})^2 \quad (2)$$

$$SSE = \sum_{i=1}^{t}\sum_{j=1}^{r_i}\left(Y_{ij} - \bar{Y}_{i.}\right)^2 \quad (3)$$

$$SSTo = \sum_{i=1}^{t}\sum_{j=1}^{r_i}\left(Y_{ij} - \bar{Y}_{..}\right)^2 \quad (4)$$

$$MST = \frac{SST}{dfT} \quad (5)$$

$$MSE = \frac{SSE}{dfE} \quad (6)$$

Where SST represents the variability between the group means (i.e., the variability explained by the treatments). It reflects how much the treatment levels affect the observed data. SSE represents the variability within the groups (i.e., the unexplained variation or residual error). It reflects the differences between individual observations and their group means. SST represents the total variability in the data. It is the sum of the variability between the groups (SST) and the variability within the groups (SSE). MST is the average variation explained by the treatment levels. It is computed by dividing SST by its corresponding degrees of freedom. MSE is the average variation within the groups (i.e., the error or residual variance). It is computed by dividing SSE by its corresponding degrees of freedom.

The formula above can be calculated based on the design of the CRD experimental design. The structure data of the CRD experimental unit can be seen in Table 2.

Table 2. The structure data of the CRD

Repetitions	Treatment				Total
	1	2	...	i	
1	Y_{11}	Y_{21}	...	Y_{i1}	$Y_{.1}$
2	Y_{12}	Y_{22}	...	Y_{i1}	$Y_{.2}$
⋮	⋮	⋮	⋮	⋮	⋮
j	Y_{1j}	Y_{2j}	...	Y_{ij}	$Y_{.j}$
Total	$Y_{1.}$	$Y_{2.}$	...	$Y_{i.}$	$Y_{..}$

2) Evaluating Performance of Treatment: *Least Significant Difference* (LSD) Test

After testing the ANOVA hypothesis results that there is difference from the treatment, it is necessary to check which treatment shows a difference. One test that is widely used and easy to apply in detecting treatments that cause differences in observations is Least Significant Difference (LSD) test [20][21]. This test compares the mean value of each treatment with the other treatments in pairs. The form of the equation to compare the average between treatments in the LSD test is as follows:

$$LSD = t_{\frac{\alpha}{2};dfE}\sqrt{MSE\left(\frac{1}{n_i}+\frac{1}{n_j}\right)} \quad (7)$$

with a confidence interval the difference in treatment mean is at intervals with the following equation (8). The expression (8) is used to compare the means of treatment groups. It helps to determine if the difference between two groups of means is statistically significant. If the difference exceeds the least significant difference threshold LSD_α, it concludes that there is a statistically significant difference between the groups at the significance level.

$$\left(\hat{\mu}_i - \hat{\mu}_j\right) \pm LSD_\alpha \tag{8}$$

Population and Sample

The population in this study was all students who took Linear Algebra courses. The sampling is done randomly by taking one class. The experimental design was conducted by forming 2 groups in 1 class as a repeat of the experiment. Meanwhile, the treatment applied is the results of student learning tests with the first treatment before the Covid-19 pandemic, the second treatment during the pandemic and the third treatment pasca the pandemic. The treatment seen from the learning system before the pandemic was carried out face-to-face, during the pandemic learning was carried out online and pasca the pandemic learning was carried out in a combined manner, namely face-to-face and online. The treatment and test do the same test questions that have been given by the researcher.

Stages of Data Analysis

The stages of data analysis in the CRD experiment design to determine the effectiveness of the Linear Algebra learning system, among others, are as follows:

1. Perform normality tests on each treatment data.
2. Conducting homogeneity tests
3. After tests (1) and (2) are fulfilled, then conduct hypothesis testing as follows:

   $H_0: \tau_1 = \cdots = \tau_t$
   $H_1: There\ is\ at\ least\ one\ i\ where\ \tau_i \neq 0$
   with decision criteria, if $F_{Results} = \frac{MST}{MSE} > F_{table} = F_{5\%;dfT,dfE}$ at the level of $\alpha = 5\%$ so H_0 rejected. That is, there is a real difference in treatment in the observation response studied.
4. Performing a difference test with LSD
5. Evaluation and conclusion

Results and Discussion

Determining Experimental Design and Assumption Test

The data collected based on the CRD experiment design came from observing the results of the scores of students who attended the Linear Algebra course class. The experiment was conducted as many as 2 tests which were categorized as learning group 1, consisting of 28 students and learning group 2, consisting of 29 students. The determination of students who enter the group is taken randomly. The treatment given is based on the learning system before the Covid-19 pandemic, which was carried out face-to-face, during the pandemic which was carried out online and after the pandemic which was carried out in a mixed manner (face-to-face and online). The following results from the observations of fifty-seven learners designed according to the CRD experiment type are shown in Figure 1:

	Ulangan	Perlakuan	Hasil Belajar
1	1	P1	71.69
2	1	P1	70.79
3	1	P1	75.88
4	1	P1	76.48
5	1	P1	59.14
6	1	P1	73.60
⋮	⋮	⋮	⋮

169	2	P3	75.13
170	2	P3	85.45
171	2	P3	66.91

Figure 1. Structure Data of CRD Experiment Observation Results

Furthermore, to apply CRD analysis, the assumptions that must be met are first checked. The normality test is carried out using the concept of the Jarque Berra test, with the test hypothesis that is:

H_0: *Normal distributed experiment error*
H_1: *Not Normal distributed experiment error*

The normality test results are displayed based on the *output* in Figure 2.

```
> sisa=residuals(RAL)
> jarque.bera.test(sisa)

        Jarque Bera Test

data:  sisa
X-squared = 0.82158, df = 2, p-value = 0.6631
```

Figure 2. Jarque Berra Test Normality Test Results

In Figure 2, a p-value of 0.6631 is obtained, which indicates that the value is greater than the significance level of the rejection criterion, which is 5%. That is, give a conclusion that H_0 it is not rejected. This proves that the error experiment is normally distributed, and the assumptions are met. The next assumption test is the homogeneity test, which is to see if there is homogeneous diversity between treatments. Testing is conducted using the Levene test, while the test hypothesis used is:

H_0: *Variety of homogeneous experiments*
H_1: *Variety is non − homogeneity experiments*

The results of the variety homogeneity test are displayed based on the *output* in Figure 3 below,

```
> leveneTest(Hasil_Belajar ~ Perlakuan, data = Data.new)
Levene's Test for Homogeneity of Variance (center = median)
       Df F value Pr(>F)
group   2  0.2593 0.7719
      168
```

Figure 3. Levene Test Results for Homogeneity of Variety

Based on Figure 3 it can be seen that the p-value obtained is quite large and is above the real level value of the rejection criterion. Therefore, the test results show that there is enough evidence to say that the variety of experiments is at a homogeneous state. If the assumption test is viewed based on the plot of each observation in the experiment, it gives similar results and can be seen in Figure 4. The normal assumption test can be seen in the second image that presents QQ-Plot [22]. It is said that the normal distributed error resulting from scattering data points almost forms a linear straight line. As for the diversity of experimental errors can be seen in the last figure in Figure 4 which is marked with constant leverage. The image gives a straight red line indicating that the diversity of experiments is homogeneous.

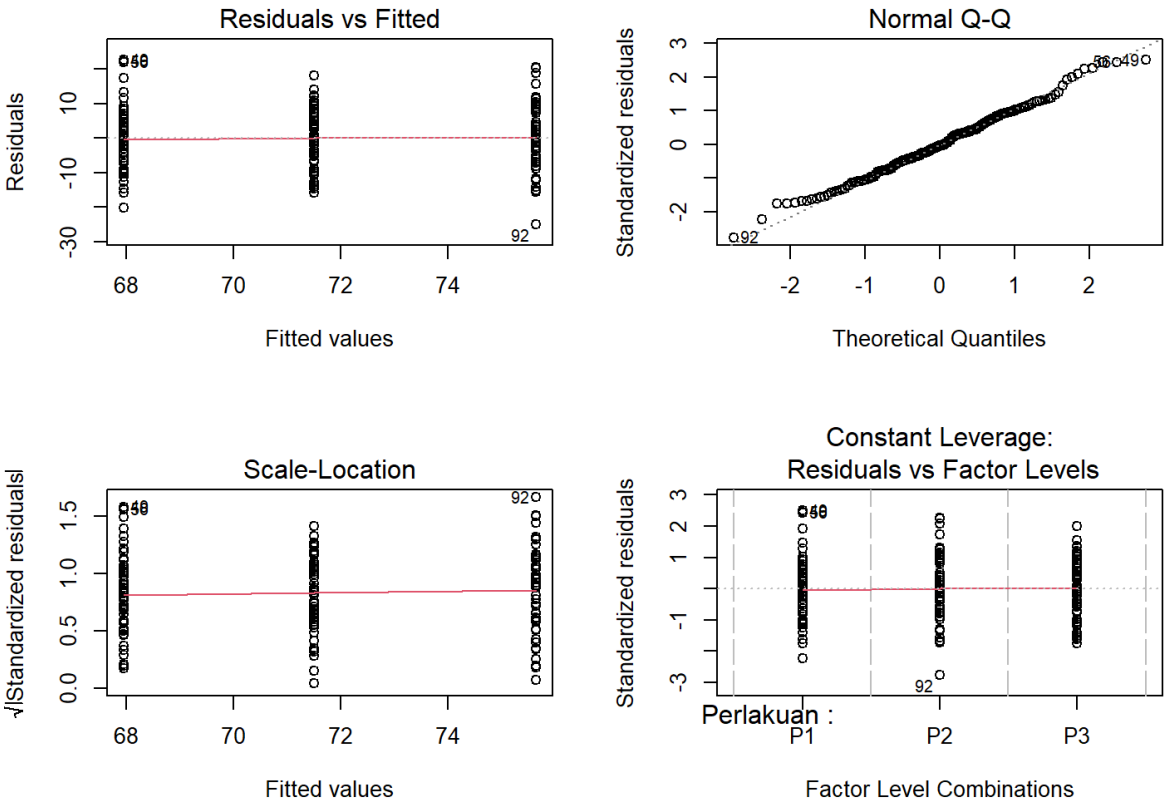

Figure 4. CRD Assumption Test Plot

Results of CRD Analysis and Evaluating Performance Test

Hypothesis testing in the CRD design was conducted to evaluate the learning system carried out after the Covid-19 pandemic was implemented effectively. It is expected that the conclusions given show a significant difference in the learning conducted before the pandemic. The results of hypothesis testing are shown in the output of Figure 5.

```
> RAL<- aov(Hasil_Belajar ~ Perlakuan, data = Data.new)
> summary(RAL)
             Df Sum Sq Mean Sq F value   Pr(>F)
Perlakuan     2   1689   844.4   10.14 6.96e-05 ***
Residuals   168  13992    83.3
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 5. Statistical Test of Post-Covid-19 Learning System

Based on the test results, it was found that the Pr(>F) value in the treatment was given an asterisk three times, meaning that the value was much smaller than the rejection criterion of the significance level to 0%. This indicates that H_0 is rejected, meaning that there are significant differences in the learning system carried out before, during and after the pandemic. The conclusion of the test indicates a difference in treatment, so further tests need to be conducted to see which treatments provide similarities or differences. Further tests were conducted by applying the Least Significant Difference (LSD) test, the test results were displayed using LSD visualization plots and given in Figure 6 below,

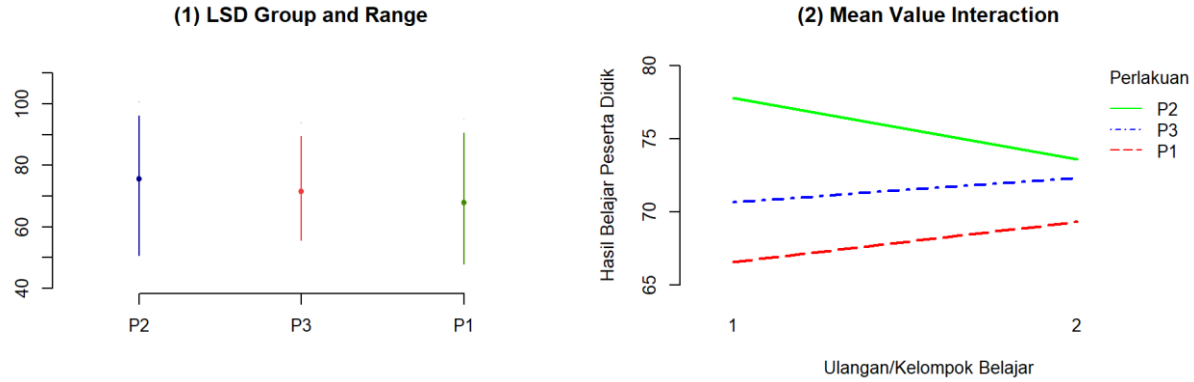

Figure 6. Plot the Difference Between LSD Test and Treatment Mean Value

The LSD test from Figure 6 provides information that:
1. The first treatment (P1) has different averages.
2. The second treatment (P2) has different averages.
3. The third treatment (P3) had different averages.

Similarly, a plot of the average score of each treatment on tests 1 and 2 which shows a significant difference in the average value of learning outcomes can be seen in Figure 6. (2). The average value of each treatment is given in the output of Figure 7.

	Hasil_Belajar	groups
P2	75.64211	a
P3	71.49702	b
P1	67.95193	c

Figure 7. Average Value of Treatment on LSD Test

LSD test results by displaying the average value of treatment in Figure 7 were in separate groups. This situation indicates the same result in the previous LSD plot and the largest average treatment value was obtained in the P2 treatment of 75.64. This indicates that the learning system for Linear Algebra courses during the Covid-19 pandemic which is carried out online provides higher learning outcomes than the treatment of other learning systems. Learning conducted online tends to provide better results because students can more freely follow learning at home. However, it has weaknesses due to the lack of observation from lecturers when learning takes place. Based on the results of the third treatment that implemented blended learning, namely face-to-face and online after the pandemic period ended, gave a lower average score compared to online. This situation occurs due to face-to-face meetings that cause students to be more controllable when participating in learning.

In addition, class meetings conducted before the pandemic provided the smallest average value of learning outcomes due to the strict supervision provided by course lecturers so that students were more controlled in following learning. However, this treatment provides student learning outcomes that tend to be lower compared to the other two learning systems.

In general, the online learning system during the pandemic provides better student learning outcomes than face-to-face or through a blended learning system. However, this must be further evaluated environmental conditions and learning models if applying the learning process online. Therefore, considering that competence from the teacher is needed to improve the effectiveness of the learning system during the pasca Covid-19 pandemic era, it is necessary to develop learning system tools for teachers. This can be an alternative to reduce the decline in student learning outcomes pasca Covid-19.

Conclusion

The CRD experiment conducted by applying three treatments based on the learning system before, during and pasca the Covid-19 pandemic in the *Linear* Algebra course resulted in the results that the online learning system during the pandemic provided better student learning outcomes than face-to-face or through a

blended learning system. However, this must be further evaluated environmental conditions and learning models so that they can be applied to the learning system pasca the Covid-19 pandemic. The learning system process during the pandemic has caused students to still be dependent on the habits of the online learning system, so to reduce the decline in learning outcomes, it is necessary to apply an integrated and conceptualized learning model to be able to control the existence of uncontrolled conditions during learning.

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