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Mathematics Pre-Service Teachers' Analogical Reasoning toward Calculus Problems

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Abstract. The purpose of this study is to describe the relationship between the educational background of Mathematics Pre-Service Teacher (MPST) at senior high school and their analogical reasoning ability (MPST) in solving calculus problems. The sample of this research is 31 MPST from STKIP PGRI Sidoarjo which consists of 18 MPST with high school natural science background, 3 MPST with social high school education background, 1 MPST with language school education background, 6 MPST with a vocational education engineering background, and 3 MPST with vocational education nonengineering background.The method of this research is quantitative method that uses non-parametric statistics namely correlation $\chi 2$ (Chi-Square) This study shows that the value of $\chi 2$ is 6,372. It can be concluded that there is no significant correlation between the educational background of MPST and analogical reasoning.

1. Introduction

Calculus courses are compulsory courses taken by mathematics education students. Calculus material that is studied consists of derivative calculus, integral calculus, and multivariate calculus, and there are some universities that teach advanced calculus. The basic concepts of multivariate calculus courses are not much different from the basic concepts of derivative calculus and integrals on the function of one variable. For example when students look for the first partial derivative value of $h(x, y) = f(x, y).g(x, y)$ with respect to variable x, students can use the concept $h_x(x, y) = f_x(x, y).g(x, y) + f(x, y).g_x(x, y)$ [1, 2]. The concept of $h_x(x, y) = f_x(x, y).\ g(x, y) + f(x, y).\ g_x(x, y)$ has the same shape as the concept of a derivative of a single variable function if $h(x) = f(x).\ g(x)$ then $h'(x) = f'(x).\ g(x) + f(x).g'(x)$. However, when students study the function derivatives two variables are in the form of $h(x, y) = f(x, y).g(x, y)$ but cannot identify that $h(x, y)$ is in the form of $h(x, y) = f(x, y).g(x, y)$ and cannot remember the concept $h'(x) = f'(x).\ g(x) + f(x).g'(x)$, then students cannot determine the value of $h_x(x, y)$. The activity of identifying, linking the similarity of forms and the application of concepts related to the initial problem and the problem which is more complex can be said to be an analogical reasoning process.

Analogical reasoning is one form of reasoning among several other forms of reasoning such as deductive reasoning and inductive reasoning[1]. Analogical reasoning is defined as one type of reasoning in which there is the process that linking one object to another as long as the two have similarities [2], [3]. The use of analogical reasoning in learning mathematical material can further make the learning better [1]. Thus, analogical reasoning is a form of reasoning that is very important to be used to learn the new mathematical context to be learned in relation to the context in which mathematics has been studied. In analogical reasoning, there are two terms used, namely the source problem and the target problem. The source problem is a problem related to a more familiar basic concept while the target problem is an advanced problem related to the basic problem [4]. The stages of analogical reasoning that must be carried out by students are encoding, inferring, mapping, and applying [5]. Encoding is identifying the characteristics that are relevant in each analogy and remembering them in memory [5]. Inferring is the alleged basic relationship between the source problem and the target problem in analogy [5], [6]. Mapping is a further conjecture of the relationship between source problems and target problems in analogy [5], [6]. Applying is the application of the alleged result of the relationship of the source problem with the target problem to solve the target problem [5], [6].

The importance of this analogical reasoning if applied by students when studying multivariate calculus can make students more easily solve multivariate calculus problems related to derivatives and integrals. But in reality, in the learning process, students do not realize that the concepts of derivatives and integrals used in the multivariate calculus have much to do with the calculus of the functions of one variable. Students tend to work on partial derivative problems of multivariate calculus according to the material being studied without linking the material that has been studied on the material of differential calculus so that students find it difficult to solve multivariate calculus derivative problems. In learning, lecturers are also less accustomed to students to use their analogy in solving many variable calculus problems.

Many students have difficulty in solving derivative questions on the multivariate calculus material, allegedly because of differences in educational backgrounds taken at the secondary school level, especially at private universities. Mathematics education students in private universities generally come from various majors. As is known, that majors for the high school level in Indonesia consist of high school natural sciences (SMA-IPA), high school social sciences (SMA-IPS), high school language (SMA-B), vocational engineering groups, and vocational non-technical groups [7], [8]. Based on K13 curriculum studies and previous curricula that are applicable in Indonesia [7], [8], it is known that students who come from SMA/MA-IPA and vocational high school engineering groups (SMK-T) get derivative and integral calculus material which is quite complex, while students who come from SMA/MA-IPS get simple derivative and integral material, and students coming from SMA/MA-B and vocational high school non-engineering groups (SMK-NT) get derived and integral calculus material when in college. Based on differences in secondary education background and student analogical reasoning involved in solving multivariate calculus problems, the question of this study is "Is there a relationship between educational background and student analogical reasoning in solving calculus problems?"

2. Method

This study is quantitative research. The research subjects were 31 Mathematics Pre-Service Teacher (MPST) of STKIP PGRI Sidoarjo consisting of 18 MPST from SMA-IPA background, 3 MPST from SMA-IPS background, 1 student from SMA-B, 6 students from SMK-T, and 3 students from SMK-NT. All research subjects used 2 derivatives problems of one variable function as a source problem and 3 derivative problems of multivariate calculus as a target problem. All questions have been validated by experts. The results of student work are then analyzed to obtain a score for each phase of analogical reasoning, are encoding, inferring, mapping, and applying. Furthermore, the scores obtained by each student are grouped into high, medium, and low analogical reasoning ability categories and are categorized with similar levels for each phase. Then to determine the relationship between MPST's educational background with analogical reasoning ability of MPST, a non-parametric statistical test was performed using the chi-square correlation ($\chi 2$).

3. Result and Discussion

In this study will be presented about the results of statistical analysis and exposure to the work of 5 MPST who represent each department.

3.1 Relationship Analysis

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3.1.1 Analysis of Relationship between Educational Background and Analogical Reasoning Ability

The following is presented data on the analogical reasoning ability score of MPST.

Table 1 Data of Analogical Reasoning Ability

No.	Initial Name	Educational Background	Analogical Reasoning Score	Maximum Score
1.	ASW	SMA-IPA	4	36
2.	AT	SMA-IPA	15	
3.	EP	SMA-IPA	36	
⋮	⋮	⋮	⋮	
31.	RHE	SMK-NT	16	

Based on table 1, data obtained regarding the interval of analogical reasoning ability level are made based on the standard deviation (SD) rules as follows.

Table 2 Interval Levels of Analogical Reasoning Ability

Analogical Reasoning Level	Interval	
	Category Range Formulas	Category Range
High	Score > $\bar{x}$ + SD	Score > 23.17
Medium	$\bar{x}$ – SD ≤ Score ≤ $\bar{x}$ + SD	6.45 ≤ Score ≤ 23.17
Low	Score < $\bar{x}$ – SD	Score < 6.45

Table 3 Statistical Descriptive Results

Statistics

		Educational_Background	Analogical_Reasoning_Score
N	Valid	31	31
	Missing	0	0
Mean			14.8065
Std. Deviation			8.36030
Minimum			.00
Maximum			36.00

Table 4 Data Grouping Analogical Reasoning Levels

Educational_Background * Reasoning_Level Crosstabulation

Count

		Reasoning Level			
		Low Analogy	Medium Analogy	High Analogy	Total
Educational_Background	SMA-IPA	3	10	5	18
	SMA-IPS	1	2	0	3
	SMA-B	0	1	0	1
	SMK-T	2	4	0	6
	SMK-NT	0	3	0	3
Total		6	20	5	31

Next will be analyzed the relationship between educational background with analogical reasoning ability with Chi-Square correlation using the following hypothesis:

H_0: There is no relationship between educational background and analogical reasoning ability.
H_1: There is a relationship between educational background and analogical reasoning ability.
$\alpha = 0.05$

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Table 5 Chi-Square Output for Analogical Reasoning Capabilities
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	6.372[a]	8	.606
Likelihood Ratio	8.710	8	.367
Linear-by-Linear Association	1.357	1	.244
N of Valid Cases	31		

a. 14 cells (93.3%) have expected count less than 5. The minimum expected count is .16.

Table 5 shows that there are 5 educational backgrounds and 3 levels of analogical reasoning ability for students so that degrees of freedom are obtained (df) = (5 – 1)(3 – 1) = 8 and $\chi^2_{test;\ \alpha=0.05} = 6.372$ and $\chi^2_{table;\, \alpha=0.05} = 15.51$. Because $\chi^2_{test} < \chi^2_{table}$ it can be concluded that there is no significant relationship between educational background and analogical reasoning ability. In addition to analyzing the relationship between educational background and analogical reasoning ability, the relationship between MPST educational background and encoding, inferring, mapping, and applying ability will be analyzed to see whether there is a relationship between educational background and MPST ability at each phase of analogical reasoning.

3.1.2 Analysis of Relationship between Educational Background and Encoding Ability

Analysis of the relationship between MPST educational background with Encoding ability uses the Chi-Square correlation with the following hypothesis.
H_0: There is no relationship between educational background and encoding ability
H_1: There is a relationship between educational background and encoding ability
$\alpha = 0.05$.

Table 6 Data Grouping Levels of Encoding Ability
Educational_Background * Encoding_Ability Crosstabulation

Count

		Encoding_Ability			
		Low Encoding	Medium Encoding	High Encoding	Total
Educational_Background	SMA-IPA	2	14	2	18
	SMA-IPS	1	2	0	3
	SMA-B	0	1	0	1
	SMK-T	1	5	0	6
	SMK-NT	1	2	0	3
Total		5	24	2	31

Table 7 Chi-Square Output Encoding Ability
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)

Pearson Chi-Square	3.172[a]	8	.923
Likelihood Ratio	3.834	8	.872
Linear-by-Linear Association	1.369	1	.242
N of Valid Cases	31		

a. 14 cells (93.3%) have expected count less than 5. The minimum expected count is .06.

Table 7 shows that there are 5 educational backgrounds and 3 levels of students' Encoding abilities so that degrees of freedom are obtained (df) = (5 – 1)(3 – 1) = 8 and $\chi^2_{test;\ \alpha=0.05}$ =3.17 and $\chi^2_{table;\alpha=0.05}$ =15.51. Because $\chi^2_{test} < \chi^2_{table}$ it can be concluded that there is no significant relationship between educational background and encoding ability.

3.1.3 Analysis of Relationship between Educational Background and Inferring Ability

Analysis of the relationship between educational background and inferring ability using the Chi-Square correlation with the following hypotheses:
H_0: There is no relationship between educational background and Inferring ability
H_1: There is a relationship between educational background and Inferring ability
$\alpha = 0.05$

Table 8 Data Grouping Level of Inferring Ability
Educational_Background * Inverring_Ability Crosstabulation

Count

		Inferring_Ability			
		Low Inferring	Medium Inferring	High Inferring	Total
Educational_Background	SMA-IPA	3	7	8	18
	SMA-IPS	1	2	0	3
	SMA-B	0	1	0	1
	SMK-T	2	4	0	6
	SMK-NT	0	3	0	3
Total		6	17	8	31

Table 9 Chi-Square Output of Inferring Ability
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	10.080[a]	8	.259
Likelihood Ratio	13.401	8	.099
Linear-by-Linear Association	2.668	1	.102
N of Valid Cases	31		

a. 14 cells (93.3%) have expected count less than 5. The minimum expected count is .19.

Table 9 shows that there are 5 educational backgrounds and 3 levels of students' inferring abilities so that degrees of freedom are obtained (df) = (5 – 1)(3 – 1) = 8 and $\chi^2_{test;\ \alpha=0.05}$ = 10.08 and $\chi^2_{table;\alpha=0.05}$ = 15.51. Because $\chi^2_{test} < \chi^2_{table}$ it can be concluded that there is no significant relationship between educational background and inferring ability.

3.1.4 Analysis of Relationship between Educational Background and Mapping Ability

Analysis of the relationship between educational background with mapping ability using the Chi-Square correlation with the following hypothesis.
H_0: There is no relationship between educational background and Mapping ability
H_1: There is a relationship between educational background and Mapping ability
$\alpha = 0.05$

Table 10 Data Grouping Mapping Ability
Educational_Background * Mapping_Ability Crosstabulation

Count

		Mapping_Ability			
		Low Mapping	Medium Mapping	High Mapping	Total
Educational_Background	SMA-IPA	3	8	7	18
	SMA-IPS	1	2	0	3
	SMA-B	0	1	0	1
	SMK-T	2	4	0	6
	SMK-NT	0	3	0	3
Total		6	18	7	31

Table 11 Chi-Square Output Mapping Ability
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.707[a]	8	.368
Likelihood Ratio	11.705	8	.165
Linear-by-Linear Association	2.200	1	.138
N of Valid Cases	31		

a. 14 cells (93.3%) have expected count less than 5. The minimum expected count is .19.

Table 11 shows that there are 5 educational backgrounds and 3 levels of students' Mapping abilities so that degrees of freedom are obtained (df) = (5 – 1)(3 – 1) = 8 and $\chi^2_{test;\,\alpha=0.05}$ = 8.707 and $\chi^2_{table;\,\alpha=0.05}$ =15.51. Because $\chi^2_{test} < \chi^2_{table}$ it can be concluded that there is no significant relationship between educational background with Mapping ability.

3.1.5 Analysis of the Relationship of Educational History with Applying Abilities

Analysis of the relationship between educational background with Applying ability uses the Chi-Square correlation with the following hypothesis.
H_0: There is no relationship between educational background and Applying ability
H_1: There is a relationship between educational background and Applying ability
$\alpha = 0.05$.

Table 12 Data Grouping Applying Ability Levels
Educational_Background * Applying_Ability Crosstabulation

Count

		Applying_Ability			
		Low Applying	Medium Applying	High Applying	Total

Educational_Background	SMA-IPA	1	12	5	18
	SMA-IPS	0	3	0	3
	SMA-B	0	1	0	1
	SMK-T	2	4	0	6
	SMK-NT	0	3	0	3
Total		5	23	5	31

Table 13 Chi-Square Output Applying Ability
Chi-Square Tests

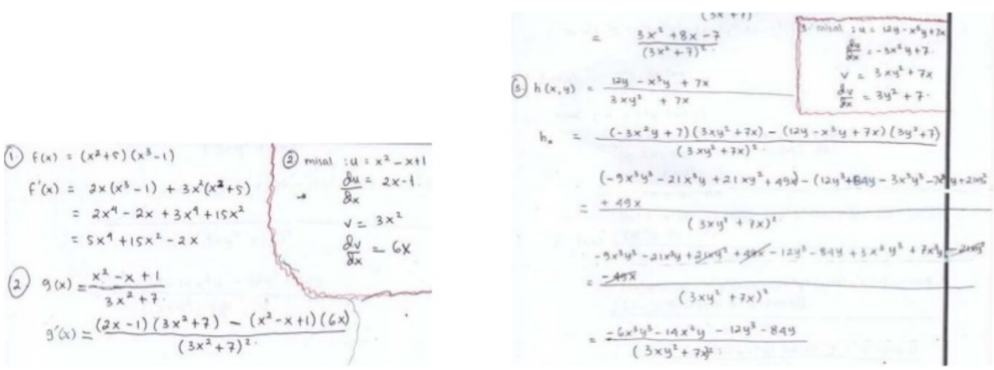
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.886[a]	8	.352
Likelihood Ratio	10.029	8	.263
Linear-by-Linear Association	3.741	1	.053
N of Valid Cases	31		

a. 14 cells (93.3%) have expected count less than 5. The minimum expected count is .10.

Table 13 shows that there are 5 educational backgrounds and 3 levels of students' Applying abilities so that degrees of freedom are obtained (df) = (5 – 1)(3 – 1) = 8 and $\chi^2{}_{test;\ \alpha=0.05}$ = 8.89 and $\chi^2{}_{table;\alpha=0.05}$ = 15.51. Because $\chi^2{}_{test} < \chi^2{}_{table}$ it can be concluded that there is no significant relationship between educational background and applying ability.

3.2 Exposure of Reasoning for Student Analogy based on Educational Background

3.2.1 MPST's analogical reasoning who was coming from SMA-IPA (S-IPA). The following is an explanation of the results of MPST's work on source problem number 2 and target problem number 1.



(a) **(b)**

Figure 1. (a) S-IPA answers to source problem number 2 and (b) S-IPA answers to target problem number 1

Based on Figure 1 (a), it can be seen that S-IPA knows the characteristics of source problem number 2 in the form of $f(x) = \frac{u(x)}{v(x)}$ which can be seen from the example done, for example, $u = x^2 - x + 1$ and $v = 3x^2 + 7$ and the use of the corresponding derivative function rules, that are $\frac{u'(x).v(x) - u(x).v'x)}{v(x)^2}$. So it can be said that the S-IPA does the encoding stage. Furthermore, from Figure 1 (b), it is known that S-IPA knows the similarity in the form of the function of the target problem number 1 to the source problem number 2, which is both in the form of $\frac{u}{v}$ even though the source problem number 2 is a function of one variable while the target problem number 1 is a function with two variables. We can conclude that S-IPA is conducting the inferring stage. Based on Figure 1 (b) it is also known that the S-IPA writes a derivative form of the target problem number 1 which is the same as the form of the source derivative problem number 2, so it can be said that S-IPA conducted the mapping stage. From Figure 1 (a) and 1 (b) it can be seen that the S-IPA applies the derived rules from the source problem and the target problem correctly, then, S-IPA can be said the application stage.

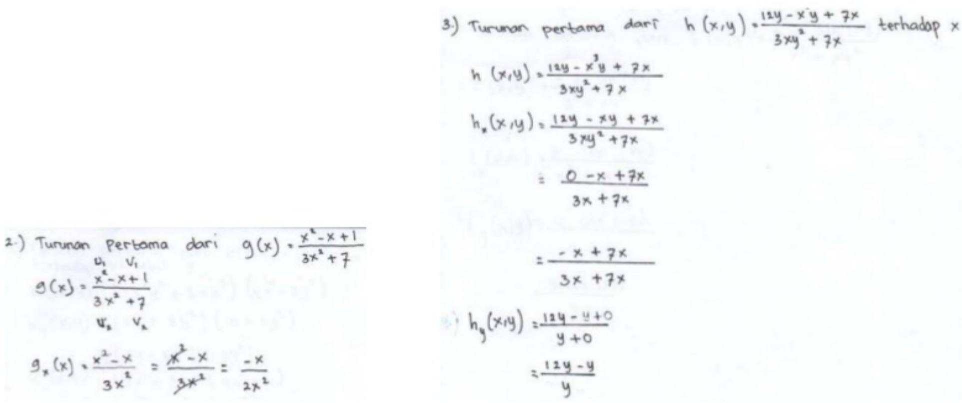
3.2.2 MPST's analogical reasoning who was coming from SMA-IPS (S-IPS). The following is an explanation of the results of MPST's work on source problem number 2 and target problem number 1.

(a) (b)

Figure 2. (a) S-IPS answers to source problem number 2 and (b) S-IPS answers to target problem number 1

Based on Figure 2 (a), it can be seen that S-IPS knows the characteristics of source problem number 1 in the form of $f(x) = \frac{u(x)}{v(x)}$ which can be seen from the use of derivative rules worked by S-IPS and for example by S-IPS, so that it can be said that S-IPS does the encoding stage. However, in Figure 2 (a), we can see that S-IPS made a wrong example by writing $u = x^2 - x$ and $v = 1$ and making mistakes in the procedure. Furthermore, from Figure 2 (b), it is known that S-IPS knows the similarity of the function of the target problem number 1 to the source problem number 2, which is both in the form of $\frac{u}{v}$ although the source problem number 2 is a single variable function while the target problem number 1 is a function with two variables. We can conclude that S-IPS conducted an inferring stage. Based on Figure 2 (b) it is also known that S-IPS writes a derivative form of target problem number 1 which is the same as the source derivative problem number 2 form although, in the denominator, S-IPS does not write the square form, however it can still be said that S-IPS does mapping stage. From Figure 2 (a) and (b) it can be seen that S-IPS applies the derived rules from source and target questions in the same way even though many conceptual and procedural errors are made, but it can still be said that S-IPS applies the applying stage with incorrect results.

3.2.3 MPST's analogical reasoning who was coming from SMA-B (S-B). The following is an explanation of the results of MPST's work on source problem number 2 and target problem number 1.

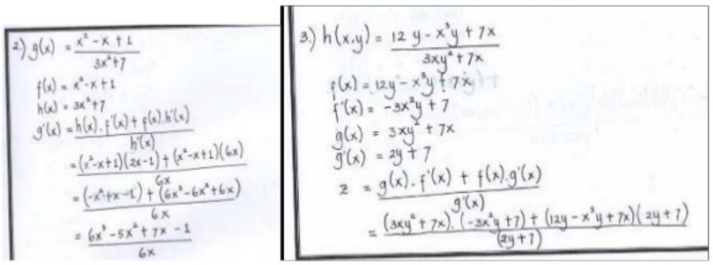


(a) (b)

Figure 3. (a) S-B answers in source problem number 2 and (b) S-B answers in target problem number 1

Based on Figure 3 (a), it can be seen that S-B knows the characteristics of source problem number 2 in the form of $f(x) = \frac{u(x)}{v(x)}$ but S-B incorrectly determines the derivative rules for source problem number 2 but it can be said that S-B performs the encoding stage with the wrong concept. Furthermore, from Figure b (b), it is known that S-B knows the similarity of the function of the target problem number 1 to the source problem number 2, that are both in the form of $\frac{u}{v}$ even though the source problem number 2 is a function of one variable while the target problem number 1 is a function with two variables. We can conclude that S-B did the inferring stage. Based on Figure 3 (b) it is also known that S-B writes the derivative form of target problem number 1 which is the same as the form of problem derived so that it can be said that S-B does the mapping stage. From Figure 3 (a) and (b) it can be seen that S-B applies the derivative rules of source and target problems in the same way even though there are many conceptual errors, but the S-B can still apply the stage of applying with incorrect results.

3.2.4 MPST's analogical reasoning who was coming from SMK-T (S-T). The following is an explanation of the results of MPST's work on source problem number 2 and target problem number 1.



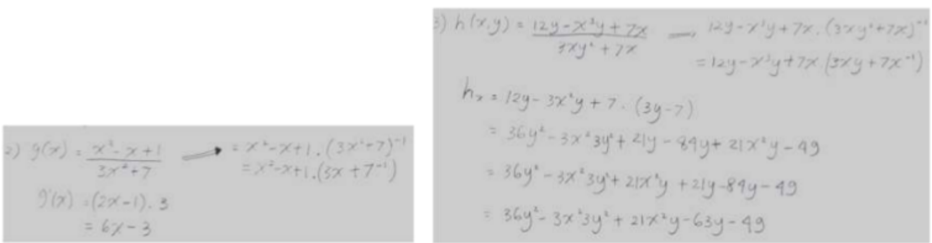
(a) (b)

Figure 4. (a) S-T answers in source problem number 2 and (b) S-T answers in target problem number 1

Based on Figure 4 (a), it can be seen that S-T knows the characteristics of the source problem number 2 in the form of $f(x) = \frac{u(x)}{v(x)}$ which can be seen from the example done, for example, u = $x^2 - x + 1$ and v =

$3x^2 + 7$, but the use of rules related to the function of the less precise is $\frac{u'(x).v(x) - u(x).v')x)}{v'(x)}$ which should be $\frac{u'(x).v(x) - u(x).v')x)}{v^2(x)}$. So it can be said that S-T is encoding with the wrong rules. Furthermore, from Figure 4 (b), it is known that S-T knows the similarity of the function of the target problem number 1 to the source problem number 2, which is both in the form of $\frac{u}{v}$ even though the source problem number 1 is a function of one variable while the target problem number 2 is a function with two variables. We can conclude that S-T did the inferring stage. Based on Figure 4 (b) it is also known that S-T writes the derivative form of target problem number 1 which is the same as the source derivative problem number 2 form, but because in source problem number 2 the rules used are wrong then for target problem number 1 the rule used is also wrong. However, S-T subjects can still be said to do the mapping stage with the incorrect concept. From Figure 4 (a) and (b) it can be seen that the S-T applies a derivative rule from the source problem to the target problem with the same rule even though the rule used is not exact ie S-T does not write the square of the denominator. Even so, it can still be said that the S-T is applying with incorrect results.

3.2.5 MPST's analogical reasoning who was coming from SMK-NT (S-NT). The following is an explanation of the results of MPST's work on source problem number 2 and target problem number 1.



(a) **(b)**

Figure 5. (a) S-NT answers in source problem number 2 and (b) S-NT answers in target problem number 1

Based on Figure 5 (a), it is seen that S-NT changes the source problem number 2 from the form $\frac{u}{v}$ to the $u.v$ form, namely $(x^2 - x + 1).(3x^2 + 7)^{-1}$ but there is an error in changing $(3x^2 + 7)^{-1}$ becomes $(3x + 7^{-1})$. At this stage, it can be said that S-NT implements the encoding stage. Furthermore, from Figure 5 (b) it is known that the S-NT knows that the form of source problem number 2 is the same as the target problem number 1 form, so it can be said that the S-NT is conducting the inferring stage. Based on Figure 5 (b) it is also known that S-NT writes the same derivative form between the source problem number 2 and the target problem number 1, so it is said that the S-NT does the mapping stage. From Figure 5 (a) and (b) it can be seen that the S-NT applies the derived rules from the source and target problems in the same way even though it is wrong to use the derived rules. Nevertheless, it can be said that S-NT did the applying stage with incorrect results.

3.3 Discussion

This study shows that educational background has nothing to do with the ability of the MPST's analogical reasoning. This can be said that someone who is able to apply his analogical reasoning ability, is not due to his educational background or how often his experience of learning similar concepts as in calculus material. As has been shown from the results of this study that is MPST from SMA-IPA and SMK-T, not all of them are able to make analogical reasoning in solving calculus problems, even though they have repeatedly obtained derivative calculus and integral calculus material. And from this study also found three groups of types of analogy reasoning, namely students who can do analogical reasoning appropriately, students who do analogical reasoning but do wrong analogies, and students who cannot do analogical reasoning.

MPST belonging to a group of students who carry out analogical reasoning but do wrong analogies consist of a number of initial errors, some beginning with an error of inferring stage, some beginning with an error from the mapping stage, and some experiencing errors at the applying stage. MPST that make mistakes at the inferring stage, tend to make mistakes because they have an incorrect understanding of the concept of the source problem so that it results in making a mistake in processing the target problem. As we know that, in seeing the similarity of source and target problems, a deeper understanding is needed before deciding to use these similarities. When someone has more knowledge about more specific topics, then that person tends to experience relational shifts, where one can pay more attention to relational information than just using perceptual information [4], [9]. When someone uses their perceptual information in solving the target problem, there can be an error in it when the perception is also wrong. Thus a deeper understanding is needed on the material derived or integral calculus in order to find the relationship between the source and target problems.

MPST that make experience errors during the mapping stage may occur because of the misconduct of the concept selection when solving the source problem. It will become when students use the analogy too far so that with confidence in the similarity of concepts used, resulting in students making the mapping stage. Taking the analogy that is too far or wrong and someone's focus on the main form of the two equations (about the source and target problems), can make that person fail to do the mapping stages [10], [11]. While the group that only did the wrong to apply tends to be due to procedural errors.

Furthermore, for groups of MPST who cannot make analogical reasoning, because these students cannot see any similarities between the source and target problems. As it is known, that in order to successfully perform each phase of analogy equipment, students must have the following 3 things, namely (1) students must recognize the similarity in form and structure between the two problems (source and target problems), (2) students must have prior knowledge about source problems and target domain, and (3) students always try to compare and differentiate between source problems and target problems [12].

4. Conclusion

This study shows that there is no relationship between educational background when MPST is in high school with their analogical reasoning ability in solving calculus problems. In addition, there is also no relationship between educational background with abilities which are analogous reasoning stages, namely encoding, inferring, mapping, and applying. This shows that in solving calculus problems, students tend to use their understanding without linking what is done with what has been learned. In other words, students tend to use their understanding when understanding the material being studied and use that understanding to solve the calculus problems that are being faced without relating it to the calculus material that has been learned. Students also use their relational ability to related the concept of source problem and target problem.

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