ICMPE | International Conference on Mathematics and Physics Education
Faculty of Tarbiyah dan Keguruan
Ar-Raniry State Islamic University, Banda Aceh

Pre-Service Physics Teachers' Ability to Formulate General Procedures of Indefinite Integration by Substitution

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Abstrak

Mahasiswa calon guru fisika dituntut untuk memiliki kemampuan prosedural matematika dalam menyelesaikan soal-soal integral tentu, karena banyak fenomena fisika yang berkaitan dengan integral tentu. Selain kemampuan tersebut, mereka juga diharapkan memiliki kemampuan untuk merumuskan prosedur umum dalam menyelesaikannya, karena kemampuan ini merupakan kemampuan tingkat tinggi yang perlu dilatihkan. Oleh karena itu, penelitian ini bertujuan untuk memperoleh gambaran mengenai kemampuan mahasiswa calon guru fisika dalam merumuskan prosedur integrasi dengan substitusi yang difokuskan pada integral tak tentu. Penelitian ini menggunakan pendekatan deskripsi kualitatif dengan subjek penelitian mahasiswa calon guru fisika di salah satu perguruan tinggi di Palembang, Sumatera Selatan. Subjek penelitian ini adalah 12 mahasiswa calon guru fisika yang mengambil mata kuliah matematika dasar pada semester pertama. Untuk mengumpulkan data, penelitian ini menggunakan metode dokumentasi dan wawancara untuk memverifikasinya. Hasil penelitian menunjukkan bahwa perumusan prosedur dibagi menjadi dua tipe; tipe pertama perumusan masih bersifat spesifik dengan menggunakan satu contoh tertentu, sedangkan tipe kedua bersifat umum, namun kedua tipe tersebut mendeskripsikan setiap langkah dengan kurang jelas dan terdapat beberapa kesalahan matematis.
Kata kunci: Kemampuan Merumuskan; Prosedur Umum; Integral Tak Tentu

Abstract

Pre-service Physics teacher are required to have mathematics procedural ability in solving definite integral problems, because many physics phenomena are related to definite integrals. Besides that ability, they are also expected to have the ability to formulate general procedures in solving them, because this ability is a high-level ability that needs to be trained. So, the aim of this study is to obtain description about the ability of pre-service physics teachers in formulate a procedure of integration by substitution focused on indefinite integrals. This study used qualitative description approach with pre-service physics teachers at one of universities in Palembang, South Sumatera as research subject. It was 12 pre-service physics teachers who take basic mathematics lectures in the first semester. To collect the data, this study used documentation and interview to verify it. The results showed that the procedure formulation is divided into two types; the first type of formulation is still specific by using one particular example, while the second type is general, but both types describing each step are still unclear, and there are some mathematical errors.
***Keywords**: Ability to Formulate; General Procedure; Indefinite Integral*

INTRODUCTION

Physics cannot be separated from mathematics, because mathematics is a tool to solve physical phenomena both quantitatively and qualitatively (Sujito, Liliasari, Suhandi, & Soewono, 2021). Not only physics, it is also a tool for solving chemical, biological and social science phenomena. One of the tools in mathematics used in solving physics problems is the integral. There are two concepts of integral that are, indefinite and definite integral (Varberg, Purcell, & Rigdon, 2006). The concepts derive the integration technique. As a scientist, pre-service physics teachers are required to have the technique

ability. There are many integration techniques that they must learn, namely integration by parts, rationalizing substitutions, integration of rational functions using partial fractions including integration by substitution.

The integration technique ability is a procedural ability because it uses mathematical concepts to solve a physics problem. The ability requires knowledge in taking the necessary steps to solve a problem accompanied by being careful in carrying out computations and recognizing mathematical objects (Friantini, Winata, & Annurwanda, 2021). One example of a physics problem that requires an integral concept in its solution is as follows: The acceleration of an object is $a(t) = (2t + 3)^{-3} m/s^2$. If the velocity at $t = 0$ is $4\ m/s$, find the velocity at 2 seconds later (Varberg, Purcell, & Rigdon, 2006). To find the velocity, the procedure is to determine the integral of the acceleration so that it will produce a velocity function. In that case, the integral of acceleration requires an integration technique by substitution. According to Weliweriya (2019), algebraic ability in the form of substitution techniques is important ability in helping to solve physics problems. This means that students who study physics must have these abilities, including pre-service physics teachers. However, procedural skills include Lower-Order Thinking Skills (LOTS). Meanwhile, formulating general procedures is a creative ability and includes level C6 in bloom taxonomy or as known as High Orders Thinking Skills (HOTS) (Anderson & Krathwohl, 2001). So, to improve pre-service physics teachers 'abilities, they must also be able to formulate procedures for using it in general, so they need to analyze every step in solving mathematical problems.

Based on the background described above, the aim of this study is to obtain description about the ability of pre-service physics teachers in formulate a procedure of integration by substitution focused on indefinite integrals.

RESEARCH METHOD

This study used qualitative description approach with pre-service physics teachers at one of universities in Palembang, South Sumatera as research subject. It was 12 undergraduate students who take basic mathematics lectures in the first semester. In this study, lecturer formed 3 groups with 4 undergraduate students each. Instrument in this study used one problem that assigned to them to discuss in group. The problem was how to formulate a procedure of integration by substitution on indefinite integral. To collect the data, this study used documentation of their answer of each group and interview to verify it. Both data were analyzed descriptively which procedure of integration by substitution on indefinite integral by Larson & Falvo (2009) and its notation was used as a guide to check. According to them, the procedure is as follows: 1) Let u be a function of *x* (usually part of the integrand), 2) Solve for *x* and *dx* in terms of u and du, 3) Convert the entire integral to u-variable form, 4) After integrating, rewrite the antiderivative as a function of *x*, 5) Check your answer by differentiating.

RESULTS AND DISCUSSION

The learning process in this study begins by reminding undergraduate students about the terminology in the integral referred to from Larson & Falvo (2009), that is the symbol of $\int$ for integral, $\int f(x)dx$ for indefinite integral, function in the integral is called integrand, *dx* for differential of *x*, the result of indefinite integral, $F(x) + C$, is called antideravative of *f* with respect to *x*, and *C* is the constant of integration. Next, the undergraduate students were explained the theorm of the general power rule of integration along with two examples of problems. To improve understanding undergraduate are assigned to solve imitation problems with the examples given in groups. Each group consists of 3 people.

After they finished, one of the group representatives explained it in front of the other group to check the correctness of the answer. After making sure that each group member can understand the solution to the assigned problem, undergraduate students are given a follow-up task in the form of formulating general procedures for determining the integration of an indefinite integral through substitution using the theorem of the general power rule of integration. As addition, the learning process that has been carried out in this study lasted for 100 minutes at 01.20 – 03.00 PM.

In this study, there were 4 discussion groups formed, namely NAL, AFJ, SAO, TRV. The NAL group formulated 8 steps in the procedure for solving indefinite integral problems using substitution, which are as follows:

1. *Petama-tama cari integral di dalam kurung*
   Firstly, find integral in parentheses
2. *Untuk integral pangkat ditambah satu (1)*
   For the powers of integral, it's added one
3. *Untuk per nya mengikuti pangkat diatasnya*
   For it's by, follow its powers above
4. *Menentukan nilai u dan du*
   Determine *u* value and *du*
5. *Masukkan nilai integral per nilai pangkat, kemudian dikurang/ditambah dengan nilai u*
   Substitute integral value by the powers value, then it's subtracted or added by u value
6. *Hitunglah nilai integral dan nilai u*
   Calculate integral value and *u* value
7. *Jika bentuknya akar, maka keluarkan nilainya kemudian dipangkatkan nilainya*
   If it is in the form of powers, then take out the value and raise the value to the powers.
8. *Tambahkan konstanta intgeral C pada setiap akhir nilainya*
   Add integral constans with C for every its value.

Istilah
With term
u = fungsi
u = function
du = turunan fungsi
du = derivatice of function
C = konstanta
C = Constanta
x = variabel
x = variable
n = pangkat
n = powers

From the results of the work of the NAL group, they do not use the term integrand for the function to be integrated, but use the word "integral" only, use non-standard terms in Indonesian, such as the word "untuk per nya". From interview, the word explain $n + 1$ of $\frac{u^{n+1}}{n+1}$. They also do not clearly define the variables for example, write down the next step without explanation, such as the fifth step, and it is not clear what should be included in the integral value. This means that the procedures formulated are general, but the description of each step is still not clear.

For AFJ group, they formulated 4 steps in the procedure for solving indefinite integral problems using substitution, which are as follows:

1. *Pertama kita harus tentukan terlebih dahulu yang mana u, du/dx, dan n (pangkat dari u)*
   Firstly, we must determine which one, *u*, du/dx, and *n* (the powers of u) previously.
2. *Seteleh itu kita masukkan rumus umum dari general power rule for integration, yaitu*
$$\int \frac{u^n du}{dx} dx = \int u^n du$$
$$\int \frac{u^n du}{dx} dx = \frac{u^{n+1}}{n+1} + C, n \neq 1$$
   After that, we subtitute general formula of general power rule for integration, that is
$$\int \frac{u^n du}{dx} dx = \int u^n du$$
$$\int \frac{u^n du}{dx} dx = \frac{u^{n+1}}{n+1} + C, n \neq 1$$
3. *Selanjutnya kita langsung masukkan saja jika sudah diketahui nilai dari u, n dan du nya ke dalam rumus umum integral*
   Hereafter, we just substitute directly, if the value of u, n, and du is known, to general formula of integral
4. *Setelah dimasukkan setiap nilainya kita operasikan*
   After we substitute every its value, we operate From the results of the work of the AFJ group, they do not define the specified variables clearly, and write the next step without explanation. In addition, the formulation of this procedure is shorter thatn the results of the work of the NAL group, does not use examples of certain problems and is general, although the description of each step is still not clear. For SAO group, they formulated 6 steps in the procedure for solving indefinite integral problems using substitution, which are as follows:

1. *Langkah pertama tentukan nilai u dari soal $\int (2x+1)(x^2-5)dx$ yang mana nilai u dari soal tersebut adalah....*
   The first step, determine the value of *u* from the problems $\int (2x+1)(x^2-5)dx$ which on *u* value of the problems is....
2. *Langkah kedua susun nilai u dalam bentuk aturan pangkat*
$$\int \frac{u^n du}{dx} dx = \int u^n du = \frac{u^{n+1}}{n+1} + C, n \neq 1$$
   The second step, set out *u* value in the form of powers rule
$$\int \frac{u^n du}{dx} dx = \int u^n du = \frac{u^{n+1}}{n+1} + C, n \neq 1$$
3. *Selanjutnya setelah disusun dalam bentuk aturan pangkat cari nilai du/dx nya*
   Next, after it is set out in the form of powers rule, find the value of du/dx
4. *Jika nilai du/dx menggunakan rumus aturan pangkat*
   If the value of du/dx is founded, then find integral value by using powers rule formula

5. $\int \frac{u^2 du}{dx} . dx = \int u^2 du = \frac{u^3}{3} + C = \frac{x^2-5}{3} + C$
   dengan
   $\frac{du}{dx} = 2x + 1, u = x^2 - 5$
   $\frac{u^{n+1}}{n+1} + C$ *dengan menjumlahkan nilai* $n + 1$
   $\frac{u^{n+1}}{n+1} + C$ by add $n + 1$
6. *Setelah dijumlahkan diperoleh hasil akhirnya dan jangan lupa ditambah C*

After it is added, we are gotten the final result and don't forget added by C
From the results of the work of the SAO group, they take one problem example, the first step is not clear, the fifth step is mistaken on $\frac{u^3}{3} + C = \frac{x^2-5}{3} + C$, solve problems from examples taken using the power rule. This means that the procedure is formulated using examples of certain problems, the procedure is still specific, and the description of each step is still unclear and mistaken.
For TRV group, they formulated 5 steps in the procedure for solving indefinite integral problems using substitution, which are as follows:
Example $\int (3x^2 + 6)(x^3 + 6x)^2 dx$
Langkah 1: Kita tentukan nilai u dan du/dx *dimana u adalah nilai variable berpangkat dapat diturunkan untuk mencari* du/dx.
The First step: we determine u value and du/dx which u is the value of the power variable that can differentiate to find du/dx.
Langkah 2: cara menurunkan nilai variabel u untuk mencari du/dx *adalah* $\frac{u^{n+1}}{n+1}$ *dimana seperti contoh diatas nilai u adalah* $\frac{u^{2+1}}{2+1} = \frac{u^3}{3}$
The Second step: the way to differentiate the value of *u* variable in finding du/dx is $\frac{u^{n+1}}{n+1}$ which is like the example above, *u* value is $\frac{u^{2+1}}{2+1} = \frac{u^3}{3}$
Langkah 3: Setelah mendapat nilai u kita substitusikan nilai u pada contoh diatas seperti $\int \frac{(x^3+6x)^3}{3} + C$
The third step: after we got u value, we substitute u value to the example above, as follows$\int \frac{(x^3+6x)^3}{3} + C$
Langkah 4: Dan dapatlah nilai turunan dari integral dari langkah 3
The fourth step: and then, we got the derivative value of the integral from the third step.

$$\int (x^3 + 6x)^2 = 3x^2 + 6$$

Langkah 5: Lalu kita substitusikan nilai *u* dan du/dx ke rumus $\int \frac{u^2 du}{dx} . dx = \int u^2 du = \frac{u^3}{3} + C$
fifth step: then, we substitute *u* value and du/dx ke rumus $\int \frac{u^2 du}{dx} . dx = \int u^2 du = \frac{u^3}{3} + C$ formula
Dapatlah hasil integralnya $\frac{x^3+6x}{3} + C$
We got the result of integral that is $\frac{x^3+6x}{3} + C$

From the results of the work of the TRV group, they use a particular problem example, the variables used as examples are not clearly defined, and the explanations in the steps are not written systematically, such as writing.

$$\int (x^3 + 6x)^2 = 3x^2 + 6 \ we\ got \frac{du}{dx}\ value$$

on the fourth step. This means that the procedure is formulated using examples of certain problems, the procedure is still specific, and the description of each step is still unclear and mistaken, like the work of the SAO group.

From the results of the work of the four groups, the results of the document analysis lead to the identification that the procedure is divided into two types of formulations, the first type of formulation is still specific, while the second type of formulation is made in general, but the two types of formulation describing each step are still unclear, and there are some mathematical errors. In addition, the procedure formulated by the four groups does not contain steps to reexamine or check by testing the derivative of the integral results obtained such as the procedure according to Larson & Falvo (2009). However, the learning process carried out has been able to activate students to discuss and convey ideas in formulating mathematical procedures according to their own language. This is because the task designed by the researcher is not a closed problem, but an open one, because open math problems make students think creatively (Shoit & Masrukan, 2021; Suryaningsih & Astuti, 2021; Samuntya, Susiswo, & Muksar, 2022) and help students understand the subject matter (Machado & Mello-Capres, 2018). This can be seen from the variety of answers produced by the four groups in formulating a general mathematical procedure of indefinite integration by substitution.

CONCLUSIONS AND SUGESTIONS

Based on results and discussions, pre-service physics teacher in the first semester have not been able to clearly formulate general procedures of indefinite integration by substitution. Suggestions for further research, the results of the formulation of the procedures for each group need to be tested from the perspective of students, whether they can be understood and used to determine Indefinite Integration by Substitution so that the conclusions made by researchers will be more valid.

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