Integrating numerical computation into the undergraduate education physics curriculum using spreadsheet excel

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Abstract. Numerical computation has many pedagogical advantages: it develops analytical skills and problem-solving skills, helps to learn through visualization, and enhances physics education. Unfortunately, numerical computation is not taught to undergraduate education physics students in Indonesia. Incorporate numerical computation into the undergraduate education physics curriculum presents many challenges. The main challenges are the dense curriculum that makes difficult to put new numerical computation course and most students have no programming experience. In this research, we used case study to review how to integrate numerical computation into undergraduate education physics curriculum. The participants of this research were 54 students of the fourth semester of physics education department. As a result, we concluded that numerical computation could be integrated into undergraduate education physics curriculum using spreadsheet excel combined with another course. The results of this research become complements of the study on how to integrate numerical computation in learning physics using spreadsheet excel.

1. Introduction
Physics as a product of science is formed based on a series of observations of natural laws which are generally presented in a mathematical equation. In introductory physics courses, students are usually hampered by their lack of mathematical tools such as in constructing a mathematical equation of physical system and interpreting a graph that may cause difficulties for students to understand the physical system [1,2].

The method used to solve a problem of physics is an analytic method, but the more complex problem that must be solved required a certain numerical method. Along with the development of science and technology, in the arrangement of mathematical models (modeling) and numerical techniques usually, use computer (numerical computation) help to analyze and solve various problems by using visualization and simulation techniques. Numerical computation gives pedagogical advantages, including the development of numerical problem-solving skills, modeling, and visualization of physical systems [3]. Numerical computation is needed by physics graduates as they work, but many types of research have shown that the students are unprepared with computational skills [4,5]. In addition to being required in workplace, numerical computation also required to be taught in the classroom learning process because numerical computation can provide various pedagogy advantages such as being able to develop analytical skills, facilitate learning through simulation and visualization of various systems and physical phenomena and improve the quality of physics education [6,5].

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One of the excellence of numerical computational is to demonstrate more realistic natural phenomena by analyzing the various factors that must be analyzed, where these factors are usually ignored in analytical methods with consideration to make analysis easier. Numerical computation can provide students with opportunities to learn based on the paradigm of solving problems more effectively and efficiently than traditional learning [3]. The advantages of using a computer in physics education should not be realized by simply giving computational problems, besides students achieve the correct numerical solution, their understanding about the physical system on which the problem is based must increase [7]. The students should begin to practice developing models of physical phenomena (modeling skill) and using computers to simulate their physical problems in studying physics process (simulation skill). The modeling and simulating skills consist of several categories: choosing a computational model, assessing computational models, using computational models to test solution, and using computational models to understand a concept [8].

Teaching numerical computations to undergraduate physics students is still a challenge [9,2]. Various researches were conducted to find the best way of teaching numerical computation to undergraduate physics students. In reality, however, in many cases that occur in many universities, due to the dense curricula, it is almost impossible to teach numerical computation as a course with its own credit [2]. Various efforts have been done to overcome this problem, such as by integrating numerical computation in basic physics courses combined with lab activities in the laboratory equipped with material resources on the web [2] and providing additional training in mechanics courses and thermodynamics [7]. Doing numerical computation, students need programming experience. Unfortunately, many studies found that most of the students have no programming experience [9]. To overcome this problem, some researchers chose to use easy and free programming languages like Vpython or paid programming languages like Origin and IGOR. However, the use of paid programming languages such as Origin and IGOR also cause problems because students just using ready-made programs, students may assume that numerical computation as black boxes that they do not understand. Therefore, the use of programs that require students to actively make their own computation is the best choice [3].

One of the main obstacles in teaching numerical computation is the language of certain programmers that must be mastered by students. One effort that can be done to help students learn numerical computation without having programming language is by using spreadsheet excel. Spreadsheet excel is selected based on the fact that almost all students have been studied it and the program is also installed on their owned computer. Spreadsheet excel can be used to simulate and visualize various physical phenomena either with analytic or numerical methods without the need for difficult mastery of programming languages [10,11,1].

There were many types of research about numerical computation on high school students or college students who have not mastered programming languages. As a result, numerical modeling used spreadsheet excel can be used to improve interest and the students’ knowledge [10,12]. In that research, the students guided to train their computational skill by the proctored program that will give students a clear instruction. The main trained skills are to recite problem of words into programming tasks, identifying, and updating the input variables.

The case of nonharmonic oscillation such as damped oscillation shows dynamic system usually described by differential equations. Students must master in calculus to solve the differential equation. In order to make the system easier, the differential equation can be replaced by finite difference method [13]. The damped oscillation can be taught easily use an analytical method by exploring graph facilities of spreadsheet excel without using numerical method [14]. Based on that former researchers, in this research, we developed a study that allows students to create their own numerical modeling using spreadsheets excel to solve various physical phenomena to improve students’ modeling and simulations skills.

In simple harmonic oscillation, the period does not depend on the amplitude. When the period of oscillation depends on the amplitude, the oscillation is nonharmonic oscillation. The real-world oscillation systems always have some dissipative forces, and oscillation will decrease in amplitude and
This phenomenon is called damped oscillation. The assumption of damped oscillation is the fractional damping force proportional to the velocity of the oscillating body. This behavior occurs in friction involving viscous fluid flow, such as sliding between oil and lubricated surfaces. The force on the body due to friction is \( F_x = -b v_x \), where \( v_x \) is the velocity and \( b \) is a constant that describes the strength of the damping force. Using Newton's second law, the net force of the body is

\[
\Sigma F_x = -b v_x - k x
\]

or

\[
m \frac{d^2 x}{dt^2} = -b \frac{dx}{dt} - \frac{k}{m} x
\]

Equation (2) can be written as

\[
\frac{d^2 x}{dt^2} + \frac{b}{m} \frac{dx}{dt} + \frac{k}{m} x = 0
\]

Equation (3) is a differential equation for \( x \). The general solution of equation (3) is

\[
x = A e^{-\left(\frac{k}{2m}\right)t} \cos(\omega' t + \phi)
\]

where \( \omega' \) refers to

\[
\omega' = \sqrt{\frac{k}{m} - \left(\frac{b}{2m}\right)^2}
\]

The value of \( \omega' \) is not constant, but depend on \( b \). If the \( \frac{k}{m} = \left(\frac{b}{2m}\right)^2 \) it's refers to critical damping, if \( \frac{k}{m} > \left(\frac{b}{2m}\right)^2 \) it's refers to under damping, and if \( \frac{k}{m} < \left(\frac{b}{2m}\right)^2 \) it's refers to over damping.

The equation (3) can be solved numerically by using a Euler-Cromer method. The equation (3) can be rearranged to

\[
\frac{d^2 x}{dt^2} = -b \frac{dx}{dt} - \frac{k}{m} x
\]

Based on the definition \( \frac{d^2 x}{dt^2} = \frac{dv}{dt} \) and \( \frac{dx}{dt} = v \) then

\[
\frac{dv}{dt} = -b \frac{dx}{dt} - \frac{k}{m} x
\]

The numerical solution of equation (3) then

\[
v_{i+1} = v_i - \frac{b}{m} v_i \Delta t - \frac{k}{m} x_i \Delta t
\]

and

\[
x_{i+1} = x_i + v_{i+1} \Delta t
\]

Based on equation (8) and (9) the characteristic of damped oscillation can be investigated by creating a simulation and then choosing the right value of \( v, b, k \) and \( m \).

2. Methodology

The participants of this research were 54 students of the fourth semester of physics education department of Sebelas Maret University in the 2015/2016 academic year. In the second semester, the students have studied how to make physics learning media using spreadsheet excel. Therefore in preliminary this course, we focus to train students using spreadsheet excel to solve various physics problem using the analytical method. In this course, the students tried to solve problems of one or two-dimensional motion used spreadsheet excel with analytical analyze. We also asked students to visualize beat phenomena using spreadsheet excel. In this lecture, the students must define the dependent and independent variable of beat phenomena; then they must explore the variables relationship. We found that the majority of students were able to visualize beat phenomena correctly. Students wrote simple programs to compare the motion of a ball in free fall and motion of ball under gravity and air drag, projectile motion by ignored air drag and projectile motion under air drag. The students also learned oscillation/periodic motion with the analytical approach. It was followed by
teaching computational modeling using Euler and Euler-Cromer. In this course, students also had to work on the same problem with the analytical and numerical analysis, then students were asked to compare the accuracy of numerical with the analytical solution. Thus, students would be able to determine the most appropriate numerical method to solve various cases.

In this research, we focused numerical computation in modeling and simulations skills. We divide modeling and simulations skills into several categories: choosing a computational model, assessing computational models, using computational models to test solution, and using computational models to understand a concept. Students’ numerical computational skills were assessed using performance test, essay question and interview. First, student developed a computational model by using a spreadsheet excel. In this assessment, students must create a computational model and write it correctly in a spreadsheet. Students continued to do a second assessment by answering several essay questions. The essay question was intended to determine how students correlate the computational model to assess computational models, use computational models to test solution, and use computational models to understand a concept.

3. Result and Discussion

3.1. Result

Based on previous research, teaching numerical computations should use a computer program which is familiar and easy to understand by students. Therefore, the first step taken in teaching numerical computing to students is to know the students’ ability to use spreadsheet excel. The students’ ability in using spreadsheet program is presented in the following table.

| No | Indicators                                | Average Score (maximum score 4) |
|----|-------------------------------------------|---------------------------------|
| 1  | Operating spreadsheet excel program        | 3,7                             |
| 2  | Defining independent and dependent variable | 3,7                             |
| 3  | Defining cell reference                    | 3,3                             |
| 4  | Writing simple mathematics equation        | 3,7                             |
| 5  | Writing more complex mathematics equation  | 3,7                             |
| 6  | Making a table                            | 3,7                             |
| 7  | Copying data                              | 3,7                             |
| 8  | Making a graph                            | 3,7                             |
| 9  | Defining slope                            | 3,7                             |
| 10 | Using trend line                          | 3,3                             |
| 11 | Converting various physics units          | 3,7                             |
| 12 | Using basic statistical function           | 3,3                             |

Based on table 1, we concluded that the students will able follow this course. Before students start the course, we gave additional course to give them a deeper understanding about defining cell reference, trendline, and some basic statistical function.

In this research, we focused numerical computation in modeling and simulation on oscillatory motion phenomena especially nonharmonic oscillation.
According to performance test and essay questions, the students’ modeling and simulations skills can be presented in figure 1.

![Diagram showing average scores for different tasks]

**Figure 1.** The average score of modeling and simulations skills

There were 62% of students who have the ability to create a precise computational model. There were 75% students able to choose a precise computational model, 75% students were able to assess computational models correctly, 60% students were able to use computational models to test solution correctly, and 40% students were able to use computational models to understand a concept correctly. The observation of students’ work showed that most students were able to choose computational model appropriately. Only 25% students choose a wrong computational model, consequently, the students will not be able to assess computational model and test the solution. The examples of the wrong and right computational model done by students shown in figure 2 and 3.
Based on figure 2 and 3, the students actually understood how to choose a computational modeling. In figure 2, the students chose Euler-Cromer method as the numerical solution of the nonharmonic oscillator. They understood that for nonharmonic oscillator the Euler method is not a good choice because the Euler method yielded a solution that did not quite conserve energy. In figure 3, the students chose Euler method as the numerical solution of the nonharmonic oscillator. They did not understand that for nonharmonic oscillator the Euler method is not a good choice. Based on the interview, we conclude that many students still confused the difference between Euler method and Euler-Cromer method.

According to interview, the most difficulties occurred when students must perform the computational model into spreadsheet environment, performing iterations to assess computational model, and interpreting the results as a graph to find the concept. The difficulties are shown in figure 4.
The students are incapable to test the computational models they have made because they couldn’t choose the right time step value. It showed on their simulation. Most of the students chose too small time step value so that the results of iterations performed based on graphs can not show the value of one-period oscillation, consequently, they have unable to show that in the non harmonic oscillator, the period of motion depends on amplitude.

Problem number 2 was tested to students after lecturer and students discussed the problem number 1. Based on the mistake done by students in doing problem number 1, problem number 2 were completed with an instruction such as the value of mass, spring constant, amplitude, and time step value. Based on the student’s answer, it can be concluded that all students chose Euler-Cromer method to solve the problem. Over than 80% students were able to simulate damping oscillation using spreadsheet excel. The wrong and right simulation of over damping shown in figure 5 and 6.

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**Figure 4.** Snapshot the simulation of inaccurate time step (\(\Delta t\)) cause incomplete one-period oscillation

**Figure 5.** Snapshot the wrong simulation of overdamping
Figure 6. Snapshot the right simulation of overdamping

According to the performance test review, the students made mistake in calculating time, after $t = 3$ s, the students wrote $t = 2$ s, 1 s, 1,05 s nor $t = 3,05s, 3,1s, 3,15$, consequently the simulation was wrong. Based on the interview, it can be concluded that the mistake caused by mistyping the value of time. The students type the number manually, they forgot to use a formula of cell reference in this case.

Numerical computation uses spreadsheet excel gave students chance to investigate the characteristic of nonharmonic oscillation. Most of the students were able to investigate the effect of $b$ to the period and amplitude the oscillation. They made computation that compared the underdamping oscillation at $b =0,1$ and 0,25 then represent the computation into a graph. In spite of almost students made the simulation correctly, only 40 % students were able to describe the graph correctly. The simulation and the analysis of students are shown in figure 7 and 8.

Figure 7. Snapshot of wrong analyse
About 40% students said that larger $b$ caused greater damping where the period decrease, 20% students said that larger $b$ caused the amplitude increase, and only 40% students said that larger $b$ caused larger damping where the amplitude decreases more rapidly and the period increases.

After following this course, some students were interviewed. The students said that this course very interested. About 80% of students said that after following this course, they more interesting to physics and mathematic and only 20% students said that they more interesting to physics. They said that study to solve damped oscillation use numerical method is very interesting because they usually just memorize the general equation of damped oscillation and its general solution use an analytical method. According to students, general equation of damped oscillation is very complicated, in spite of, they know that the general equation of damped oscillation is a homogeneous differential equation of the second order but they doubted able to solve the equation correctly. Most of the students said that use numerical method is very simple and accurate to find the solution of a damped oscillation. Most of the students suggested that the problem involved numerical computation should be completed by an instruction such time step and the value of each variable the problem.

3.2. Discussion
Based on the interview, we conclude that most students very interested to follow the course. They said that they got new knowledge how to solve a complex physics problem such as nonharmonic oscillator using a simple method. The students said that they get the experience how to simulate nonharmonic oscillator to investigate the characteristic of the system. Our finding is consistent with previous research [2, 3, 5]. Most of the students that chose wrong computation model said that they still confuse about the importance of numerical computation. They said that they do not get a new concept of this course, they just know the concept of analytical method. Based on test performance, we found that most of the students that chose wrong computation model also make a mistake in creating a graph because they couldn’t choose the accurate time step. For example, when they asked to investigate the effect of amplitude on the period of nonharmonic oscillation they make a graph of amplitude versus period, nor make a graph of amplitude versus time then calculate the period. Our finding is still consistent with previous research [5, 11]. Therefore, for the next research, we advise investigating the motivation of students after following numerical computation course. It is also very important to investigate how to train students to choose the precise computational model.

3.3. Conclusion
We concluded that numerical computation could be integrated into undergraduate education physics curriculum using spreadsheet excel combined with another course. The results of this research become
a complement of the study on how to integrate numerical computational in learning physics for students who have not mastered programming languages.

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