Accuracy of Computational Modeling in Introductory Mechanical Wave Interference

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Abstract. Nearly all aspects of research in physics involve the use of computers and are invaluable in laboratory and theoretical research. Even though it is very important as a scientific discipline, the integration of computing into physics learning is still a challenge, especially regarding the ability to construct solutions to physics problems. A very important issue is how to assess the computational modeling of mechanical wave interference patterns. The expansion of computing in learning at least requires a computational model that can show a comparison between analytical problem-solving models and computational modeling. It is necessary to carry out computational modeling assessments and analytical manual solutions. The assessment standard uses a critical value of interference wave amplitude between manual analysis and computational modeling. The creation of computational models provides standardized operationalization of mechanical wave interference problem solving that can be repeated with a higher level of accuracy than manual methods.

Keywords: Computational; modeling; mechanical wave; interference

1 Introduction

Physics research is becoming increasingly related to computing systems [8]. The field of computing is growing rapidly in terms of its existence and sophistication, even to the point where it is almost on par with theory and experiment in the field of physics and is considered the third pillar that bridges between the laboratory and theory [14]. The main goal in the field of physics education is to integrate computing into the learning system and be able to provide accuracy in the problem-solving process related to certain content or teaching materials [16], [2].

Several applications that can be used in learning physics such as PhET Colorado, crocodile physics, algodoo which aim to serve as learning media. The physics content displayed

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combines visualization or simulation and empirical calculations for the purpose of deepening physics knowledge [9][4]. Based on this fact, the idea can be drawn that the use of computers through several applications can provide an optimal role in physics learning [15]. Mathematica, Matlab and Python are examples of high-level programming languages that can provide computational assistance in teaching mathematics and physics at universities [2]. Unfortunately, the integration of computer use in all courses has not been recommended curricularly in higher education institutions [8] except for only courses that specifically apply computer use.

There are several obstacles when wanting to implement computers into a physics learning program, starting from selecting teaching materials, setting learning objectives relevant to computer use, and the application platform used when generating program code [1]. The accuracy of computational modeling that meets the theoretical boundary conditions that are part of the manual analysis into program creation is the main factor that is difficult to develop. At the introductory stage, the use of computational capabilities for the mechanical wave course, especially the phenomenon of wave superposition in the interference case, is very appropriate to apply.

Maximum mastery of mechanical wave interference teaching material requires verbal, numerical, visual, and graphic analysis [3][11]. The use of computers has a big role in making this happen[6][12][10], because it has the potential to display analysis results sequentially. This can be realized by combining manual and computer-based numerical analysis.

The main problem to be addressed in this study is how to test the accuracy of manual calculation results from problem-solving analysis of mechanical wave sine interference, when viewed simultaneously using an Excel-assisted computing model and a code program.

Basic framework of wave interference

The equation of a sinusoidal wave travelling [5] to the right along the x-axis is given by,

$$y_1(x,t)=a_n \sin(kx-\omega t) \quad (1)$$

Where a_n is the peak amplitude, $k = 2\pi/\lambda$ is the wavenumber and $\omega = 2\pi f$ is the angular frequency of the wave.

Consider another wave of the same frequency and amplitude but with a different phase (φ) travelling to the right.

$$y_2(x,t)=a_n \sin(kx-\omega t+\varphi) \quad (2)$$

where φ is the phase difference between the waves in radians

The two waves superimpose and add; the equation gives the resultant wave,

$$y_3(x,t) = y_1(x,t) + y_2(x,t) \quad (3)$$

$$y_3(x,t) = [2a_n \cos\left(\frac{\varphi}{2}\right)] \sin\left(kx - \omega t + \frac{\varphi}{2}\right) \quad (4)$$

Constructive Interference: When the phase difference is an even multiple of π (φ = ….., –4π, –2π, 0, 2π, 4π,……), then cos φ/2 =1, so the sum of the two waves is a wave with twice the amplitude.

Destructive Interference: When the phase difference is an odd multiple of π (φ =….., –3π, –π, 0, π, 3π, 5π,……), then cos φ/2 = 0, so the sum of the two waves will be zero.

2 Methods

Research participants

This research involved 20 students taking Waves and Physical Optics courses for the even semester 2023/2024.

Implementation

The research was carried out in three instructional stages

Preparation phase; provides wave interference learning materials. This material comes from university textbooks, studies from the web and studies from journals. Study of computing material based on Matlab, Excel, Python. Divide students into 5 groups with different tasks (manual analysis group based on interference formulas, analysis group using Excel, solution analysis group with program code, significance analysis group for interference amplitude values).

Lecture implementation stage; The lecture begins with a presentation of material by the lecturer, students observe and analyze when the question-and-answer session opens. The lecturer presented a case of interference symptoms which is an implementation of wave interference theory. Students are asked to find solutions to solve cases using a manual analysis approach. Find analysis of case solutions using manual computing methods using Excel and write code for solving wave interference equations using the Matlab platform or other programs.

Final stage; Presentations of the results of case solutions were presented by several students as group representatives. The presentation platform presents materials and solutions followed by a discussion to consider the work process and results of manual analytical solutions and computational modeling. The target is to find the solution with the most significant accuracy of the interference pattern and its characteristics.

3 Result and Discussion

Case of superposition of mechanical waves:

Two waves are traveling in the same direction along a stretched string. The waves are 90.0° out of phase. Each wave has an amplitude of 4.00 cm. Find the amplitude of the resultant wave.

Manual solutions

First, it can be assumed that the wave travels to the right using the wave equation sinus

$$Y_1 = 4\sin(kx - \omega t)\,(5)$$

The second wave moves in the same direction with a phase difference of $90^0 = \pi/2$ rad and can be written

$$Y_2 = 4\sin\left(kx - \omega t + \frac{\pi}{2}\right)(6)$$

Based on the principle of superposition is obtained

$$Y_1 + Y_2 = Y_{\int} \text{¿} = 4\sin(kx - \omega t) + 4\sin\left(kx - \omega t + \frac{\pi}{2}\right)(7)\text{¿}$$

$$Y_{\int} \text{¿} = 8\cos\left(\frac{\pi}{4}\right)\sin\left(kx - \omega t + \frac{\pi}{4}\right)(8)\text{¿}$$

$$Amplitudo = 8\cos\left(\frac{\pi}{4}\right) = 5.66\,cm\,(9)$$

The manual solution produces an interference wave amplitude value of 5.66 cm. This value can be evaluated using computational models. This manual solution is prone to errors during the calculation process when adding wave equations based on the principle of wave superposition.

Accuracy of calculation results needs to be developed to avoid calculation process errors. The use of computers as a means of modeling calculations as a check or accuracy of manual calculation results can be developed. The accuracy of calculations by carrying out equation transformations using Excel and mechanical wave interference program code is reliable. Program code with a certain programming language, for example Matlab, is able to provide the best accuracy.

Computational modeling of wave interference can provide a more accurate analysis of constructive, destructive [17] and intermediate interference phenomena compared to other solutions. For example, in the same interference scenario, a rad phase difference produces constructive interference as depicted in **Figure 1**. and **Figure 2.** A phase difference of π rad produces the destructive interference pattern in Figures 3 & 4. When the phase difference is between $0<\varphi<\pi$, an intermediate interference pattern is produced, as seen in Figures 5 & 6. Based on the interference wave function, wave displacement can be easily determined based on time and location, this can be obtained by looking at the resulting numerical analysis.

At a phase of radians, a maximum amplitude of 8 cm is achieved, indicating constructive interference as shown in **Figure 1.** and **Figure 2.** At a phase of π radians, the maximum amplitude is reduced to 0 cm, indicating destructive interference as displayed in **Figure 3.** and

Figure 4. A phase difference of 1.57 radians (or 90°) results in intermediate interference with an amplitude of 5.66 cm, illustrated in **Figure 5.** and **Figure 6.**

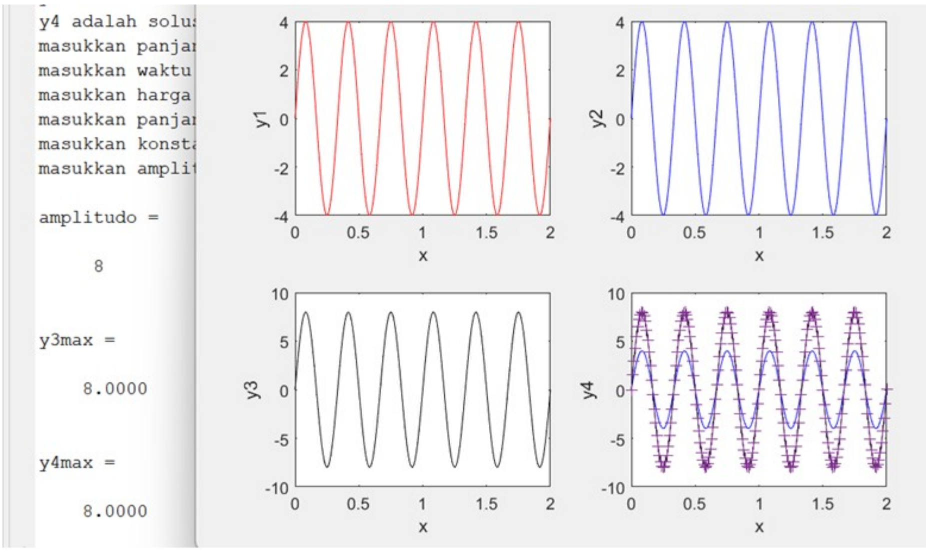

Fig. 1. Representation of constructive interference output from program code

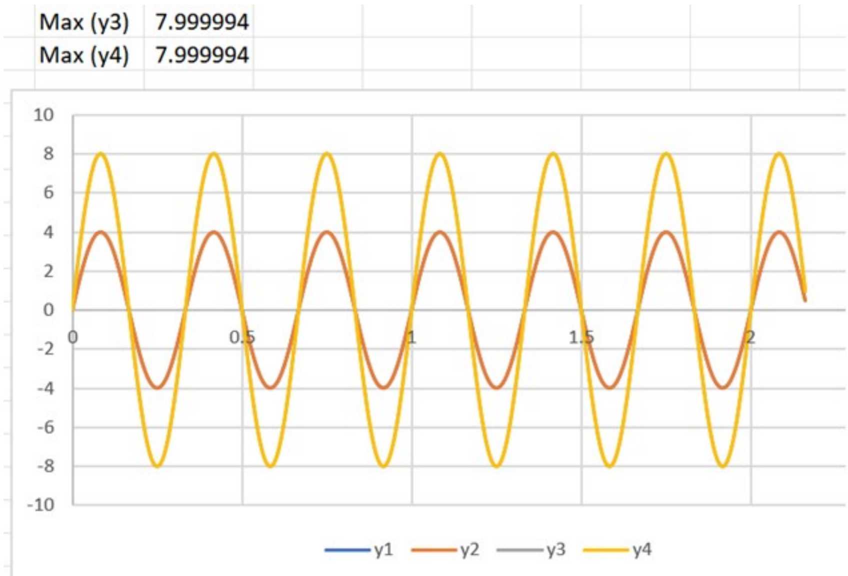

Fig. 2. Constructive representation of output wave interference from excel

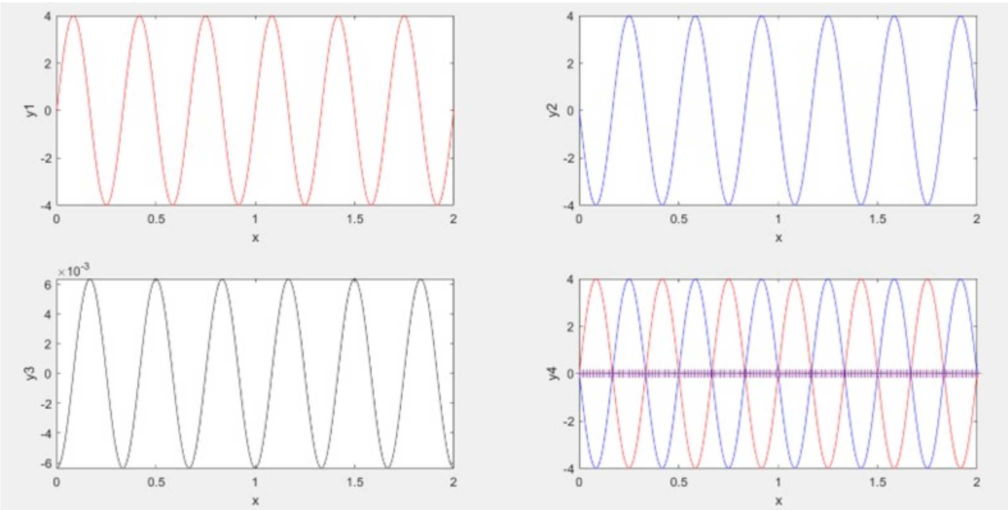

Fig. 3. Representation of destructive interference output from program code

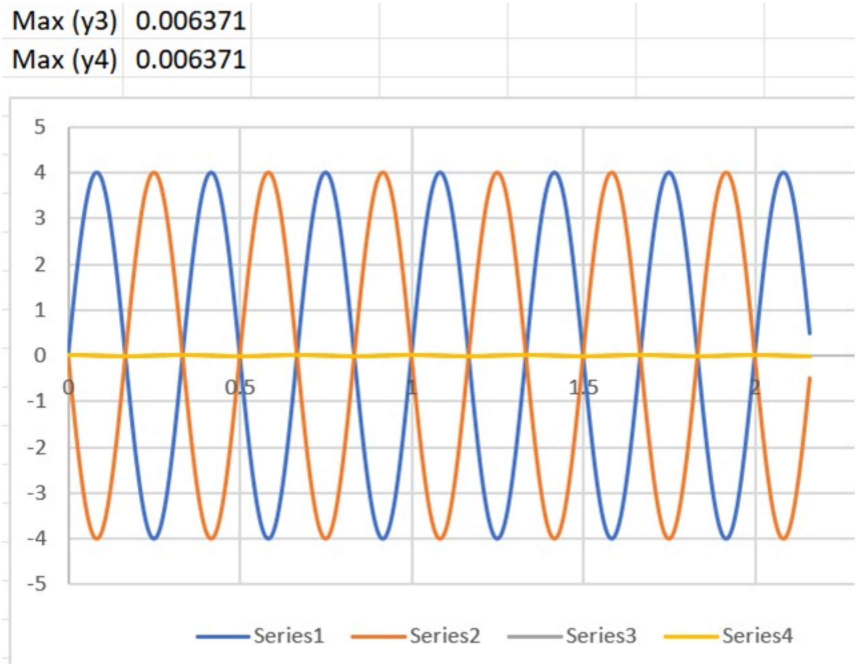

Fig. 4. Representation of destructive interference wave output from Excel

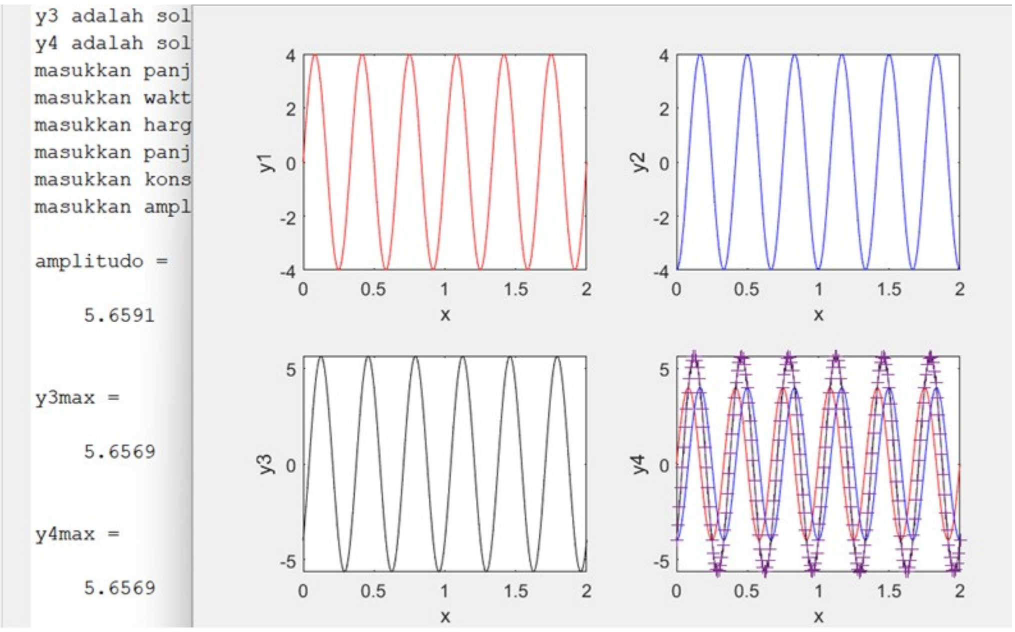

Fig. 5. Representation of intermediated interference, output from program code

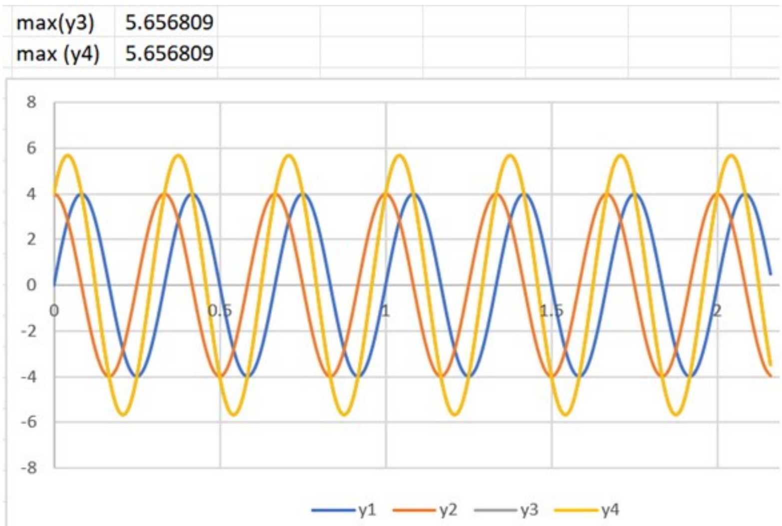

Fig. 6. Intermediate representation, output wave interference from Excel

Discussion

Solving cases of mechanical wave superposition can be done by manual analysis[13] using wave superposition techniques. The accuracy of the solution is largely determined by the accuracy and arrangement of the cosine or sine function in the form of algebraic addition. The basic rule of addition of sines and cosines is often a source of error in interference wave function analysis. Likewise, the functional grouping between vibrations and waves and the wave amplitude resulting from superposition.

The next stage involves numerically analyzing[7] the solution using computer assistance. The first step is to design a computational framework using the Excel system, resembling manual solutions. The second step involves devising a solution for the interference case by initially writing program code as part of the solution design. The stages of interference solution utilizing computer-assisted techniques entail employing Excel programs or code programs with consistent data intervals. The program code provides more precise peak amplitude calculations for constructive interference compared to Excel.

4 Conclusion

The phase difference of the superposed input wave produces 3 types of interference, namely destructive, constructive and intermediated. The accuracy of the calculation results between manual analysis, modeling analysis using Excel and program code has different levels of accuracy.

The destructive interference pattern for a sine wave source and different phase π rad produces a characteristic interference pattern with a peak amplitude of zero. A constructive interference pattern occurs if the input sine wave with a phase difference of 0 rad is characterized by a maximum peak amplitude of the interference wave that is twice the peak of the input wave. If the phase difference of the input sine wave is between 0 and π then the peak of the wave is between 0 and 8, it is said to be intermediated interference.

References

[1] Brewe, J.G. and E.: Analyzing interviews on computational thinking for introductory physics students: Toward a generalized assessment. Phys. Rev. Phys. Educ. Res. 20, 010128, (2024).

[2] Caballero, M.D. et al.: Implementing and assessing computational modeling in introductory mechanics. Phys. Rev. Spec. Top. - Phys. Educ. Res. https://doi.org/10.1103/PhysRevSTPER.8.020106 (2012).

[3] Dai, R. et al.: Assessment of student understanding on light interference. Phys. Rev. Phys. Educ. Res. https://doi.org/10.1103/PhysRevPhysEducRes.15.020134 (2019).

[4] Hurt, T. et al.: The computational thinking for science (CT-S) framework: operationalizing CT-S for K–12 science education researchers and educators, https://doi.org/10.1186/s40594-022-00391-7 (2023).

[5] Jearl Walker, David Halliday, R.R.: Fundamental of Physics. John Wiley & Sons, Inc, NJ (2014).

[6] Kabigting, L.D.C.: Computer Simulation on Teaching and Learning of Selected Topics in Physics. Eur. J. Interact. Multimed. Educ. https://doi.org/10.30935/ejimed/10909 (2021).

[7] Li, D. et al.: Numerical investigation on the wave interferences of submerged bodies operating near the free surface. Int. J. Nav. Archit. Ocean Eng. https://doi.org/10.1016/j.ijnaoe.2021.01.002. (2021).

[8] Odden, T.O.B. et al.: Physics computational literacy: An exploratory case study using computational essays. Phys. Rev. Phys. Educ. Res. (2019).

https://doi.org/10.1103/PhysRevPhysEducRes.15.020152.
[9] ORULEBAJA, Y.T. et al.: Effects of Multiple representations and Problem- solving learning strategies on Physics students' problem-solving abilities. Int. J. Innov. Educ. Res. https://doi.org/10.31686/ijier.vol9.iss4.3045. (2021).
[10] Rodriguez, M., Potvin, G.: Frequent small group interactions improve student learning gains in physics: Results from a nationally representative pre-post study of four-year colleges. Phys. Rev. Phys. Educ. Res. (2021). https://doi.org/10.1103/PhysRevPhysEducRes.17.020131.
[11] Susac, A. et al.: Student recognition of interference and diffraction patterns: An eye-tracking study. Phys. Rev. Phys. Educ. Res. (2020). https://doi.org/10.1103/PhysRevPhysEducRes.16.020133.
[12] Ugwuanyi, C.S., Okeke, C.I.O.: Enhancing university students' achievement in physics using computer-assisted instruction. Int. J. High. Educ. (2020). https://doi.org/10.5430/ijhe.v9n5p115.
[13] Wang, Z. et al.: Interference of internal waves due to two point vortices: linear analytical solution and nonlinear interaction. R. Soc. Open Sci. (2022). https://doi.org/10.1098/rsos.211476.
[14] Weller, D.P. et al.: Development and illustration of a framework for computational thinking practices in introductory physics. Phys. Rev. Phys. Educ. Res. (2022). https://doi.org/10.1103/PhysRevPhysEducRes.18.020106.
[15] Yeşilyurt, E. et al.: Teacher self-efficacy, academic self-efficacy, and computer self-efficacy as predictors of attitude toward applying computer-supported education. Comput. Human Behav. https://doi.org/10.1016/j.chb.2016.07.038.(2016).
[16] Young, N.T. et al.: Identifying features predictive of faculty integrating computation into physics courses. Phys. Rev. Phys. Educ. Res. https://doi.org/10.1103/PhysRevPhysEducRes.15.010114 (2019).
[17] Zhang, R.F. et al.: The interference wave and the bright and dark soliton for two integro-differential equation by using BNNM. Nonlinear Dyn. https://doi.org/10.1007/s11071-023-08257-5 (2023)