



Two-Dimensional Visualization of Solid Expansion Using Spyder as a Physics Learning Medium in Secondary Schools

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Abstract: *Physics education in secondary schools still faces several obstacles, particularly in understanding the concepts of temperature and heat, one of which is the expansion of solids. The main problem students face is difficulty visualizing how the size of solids changes as temperatures rise, so learning tends to consist only of memorizing formulas without a deep understanding. This study aims to explain the use of two-dimensional (2D) solid expansion graphs using Python-based Spyder software as a medium for physics learning. The method used is simulation and mathematical modeling of area expansion based on physical equations, with the results displayed as graphs. The simulation shows a linear relationship between temperature changes and the area of a solid object, in accordance with the area-expansion theory $A_t = A_0 (1 + 2\alpha\Delta T)$. Graph visualization helps students understand how temperature affects changes in object size and how expansion varies across materials, depending on their respective coefficients of thermal expansion. In addition, Spyder encourages active student participation, improves critical thinking skills, and provides a basic introduction to programming. Thus, the use of solid expansion graphs in Spyder can be an effective, interactive, and relevant alternative learning medium to improve the quality of physics learning at the secondary school level.*

Keywords: *2D graphs, concept visualization, expansion of solids, physics education, Spyder.*

Visualisasi Pemuaiian Zat Padat Dua Dimensi Menggunakan Spyder sebagai Media Pembelajaran Fisika di Sekolah Menengah

Abstrak: Pembelajaran fisika di sekolah menengah masih mengalami beberapa hambatan, terutama dalam memahami konsep suhu dan kalor, salah satunya adalah pemuaiian zat padat. Masalah utama yang dihadapi siswa adalah kesulitan dalam membayangkan perubahan ukuran benda padat karena naiknya suhu, sehingga pembelajaran cenderung hanya berupa menghafal rumus tanpa memahami secara mendalam. Penelitian ini bertujuan untuk menjelaskan penggunaan grafik pemuaiian zat padat dua dimensi (2D) dengan menggunakan perangkat lunak *Spyder* berbasis *Python* sebagai media pembelajaran fisika. Metode yang digunakan adalah simulasi dan pemodelan matematis pemuaiian luas berdasarkan persamaan fisika, lalu ditampilkan dalam bentuk grafik. Simulasi yang dilakukan menunjukkan adanya hubungan linier antara perubahan suhu dengan perubahan luas benda padat, sesuai dengan teori pemuaiian luas $A_t = A_0 (1 + 2\alpha\Delta T)$. Visualisasi grafik membantu siswa memahami bagaimana suhu memengaruhi perubahan ukuran benda serta perbedaan pemuaiian pada berbagai jenis bahan, tergantung pada nilai koefisien muai masing-masing. Selain itu, penggunaan *Spyder* juga mendorong partisipasi aktif siswa, meningkatkan kemampuan berpikir kritis, serta memberikan pengenalan dasar tentang pemrograman. Dengan demikian, penggunaan grafik pemuaiian zat padat yang dilakukan dengan bantuan *Spyder* dapat menjadi alternatif media pembelajaran yang efektif, interaktif, dan relevan untuk meningkatkan kualitas pembelajaran fisika di tingkat sekolah menengah.

Kata kunci: grafik 2D, pembelajaran fisika, pemuaiian zat padat, *Spyder*, visualisasi konsep.

INTRODUCTION

Physics education in secondary schools aims to improve students' logical, analytical, and critical thinking skills by teaching practical physics concepts encountered in everyday life (Perry et al., 2019). This goal is important because early understanding of physics concepts, including temperature and heat, is essential for explaining everyday phenomena. One of the concepts taught in the material on temperature and heat is the expansion of solids. This phenomenon can be observed when stirring hot coffee with a hot spoon (conduction), when cold air from air conditioning is pushed down, and when warm air is pushed up, resulting in air circulation (convection). The body is exposed to sunlight (radiation) (Bungum & Selstø, 2022). However, one of the main obstacles is the difficulty in visualizing changes in the size of solids when their temperature increases (Garcia-Belmonte, 2017). Many students memorize the formulas in the book without understanding the underlying physics (Stanciulescu et al., 2024). Another obstacle stems from less innovative learning methods, which cause students to struggle and develop a negative stigma towards learning physics (Liang et al., 2025).

Physics education in schools often relies on lectures and formulas that are difficult for students to understand, leading students to be less active in observing phenomena and to struggle to understand them (Sukarno & Widdah, 2020). The limited use of interactive learning media and the lack of simple, practical activities make it difficult for students to connect the concept of expansion to their daily lives (Norman & Furnes, 2016). The impact of physics learning focused on lectures and memorizing formulas is low on students' conceptual understanding. This is evident in their frequent mistakes when solving applied problems (Werth et al., 2022). To overcome this problem, a more contextual, interactive, and experimental learning approach is needed (Anwar et al., 2023). Teachers can use simple media, such as graphs showing changes in an object's area as it heats. These graphs can be created using applications such as Spyder, allowing students to see the direct relationship between temperature and expansion (Wang et al., 2020). By applying appropriate learning strategies, it is hoped that students will not only memorize formulas but also develop a deep understanding of the concept of substance expansion (Viennot, 2020). In addition, they will find it easier to connect physics concepts with real-life phenomena. In addition, technological developments in education can provide great opportunities to improve the quality of physics learning (Barak, 2010).

The use of software such as Spyder in Python can help teachers to present more visual learning materials and use modeling. By looking at graphs directly derived from data on temperature changes and object size, students can see the relationship between variables in real terms, not just in theory (Jegade & Okebukola, 1989). The use of technology-based media is expected to increase curiosity, facilitate understanding, and encourage student participation in learning (Celestino-Salcedo et al., 2024). However, this technology has not been fully utilized across schools. Some teachers still find it difficult to use it due to time constraints, limited facilities, or the ability to create digital teaching materials (Molin et al., 2020). On the other hand, students are not yet accustomed to exploring, so they need guidance and a deeper understanding of active, independent learning. In this situation, there is a need for innovation in physics education that goes beyond theory and provides meaningful learning experiences through practice, simulation, and visualization (Gok, 2013; Haryandi et al., 2019).

Active media, such as simulations and visualizations, can help students better understand concepts and make learning more independent, both in class and at home (Rosen et al., 2013). Other research has developed virtual simulations of substance expansion, which have been shown to improve learning outcomes by clearly and directly

illustrating changes in object size (Norman & Furnes, 2016). In line with this, multimedia-based physics learning can also increase students' enthusiasm and motivation to learn by making the learning process more dynamic and engaging (Sari & Madlazim, 2022). This approach allows students not only to listen to and observe the learning material but also to participate actively through practical activities, thereby taking a direct role in the learning process. Therefore, software such as Spyder, which uses Python syntax, can be an alternative for teachers to display simulations and expansion graphs directly in the classroom. Not only that, but modern learning media also encourages a student-centered approach, allowing students to explore, observe, test, and draw conclusions about various physics concepts based on the data presented (Yusuf & Widyaningsih, 2020).

Using this approach can help foster critical thinking, analytical, and problem-solving skills in physics learning in the 21st century (Stanciulescu et al., 2024). However, the use of technology in school learning still faces many difficulties. Inadequate laboratory facilities, a shortage of computers, limited internet access, and a lack of teacher training remain real obstacles to optimizing technology use (Manu et al., 2025). In addition, students' learning methods, which are often passive and rely on teacher explanations, also pose an obstacle. Therefore, the learning process needs to be well-designed to encourage students to actively participate, discuss, explore, and analyze data (Rizal et al., 2020). In this way, students will become accustomed to learning independently and investigating on their own. Thus, it can be concluded that physics learning using simulations, graphics, and interactive media such as Spyder will provide a more meaningful learning experience (Nie, 2021). This approach not only helps students better understand the concept of solid expansion but also connects physics theory with phenomena they experience in their daily lives. Innovations like this are expected to overcome the weaknesses of traditional learning methods and improve the quality of physics education in secondary schools. Furthermore, using media such as Spyder to learn about the expansion of solids not only helps students understand physics concepts but also introduces them to the basics of programming.

THEORY

Spyder

Spyder is an IDE that can be used on various media and is managed under a non-copyleft license (non-copyleft free software is software created by its developers with permission to be distributed and modified). Since 2012, the Python scientific community has continued to develop Spyder through contributions (Schnieder & Williams, 2023). Spyder is an integrated development environment (IDE) dedicated to various scientific purposes, data analysis, numerical computation, and application development using the Python programming language (Juneja et al., 2026). Learning with technology, such as using media like videos, can be applied to teaching physics. Therefore, teachers must continue to innovate and improve their use of learning media aligned with developments in science and technology, including learning videos (Kadiyala & Kumar, 2017; Swandi et al., 2021). Traditional learning methods are often ineffective at helping students understand physics concepts, so an innovative approach is needed to improve student learning outcomes. In physics education, Spyder is very useful for displaying relationships between variables in various physics topics. For example, when learning about temperature and heat, students can use Spyder to create graphs showing the expansion of solids as temperature changes (Jhamb et al., 2020).

These visual displays can help students see how length, area, or volume change directly, thereby strengthening their understanding of the concept. This learning method supports the theory of student-centered learning, which emphasizes active learning experiences

designed to build understanding. In addition, the use of Spyder aligns with the project-based learning approach in physics instruction (Kulindala et al., 2025). Project-based learning is a form of learning that focuses on the process, spans a long period of time, leads to problem-solving, and uses meaningful learning units that integrate concepts from various domains, such as knowledge, disciplines, or particular fields (Maharajan et al., 2022). Project-based learning is a student-centered approach that provides meaningful, relevant learning experiences. Thus, students can create physics simulations, model natural phenomena, or analyze experimental data using Python (Veerasingh, 2024). By completing these tasks, students not only understand physics concepts but also master technological skills that are essential in today's world, and they become more active in acquiring knowledge by utilizing their potential and abilities. Furthermore, integrating programming into physics education not only enhances conceptual understanding but also encourages students to think more logically, structurally, and critically about solving real-world problems (Wang et al., 2020).

Thermal Expansion of Solids

Thermal expansion in solids is a physical phenomenon in which an object changes in size with temperature changes. At the microscopic level, atoms in the crystal structure of a solid vibrate more vigorously as temperature increases, thereby increasing the interatomic distance (Dove & Fang, 2016). As a result, the dimensions of the solid object, such as length, area, or volume, will increase. The mathematical model used to describe expansion in solids is linear, i.e., the relationship between changes in length and temperature is linear, making this phenomenon well-suited for simulation using numerical methods, such as those implemented in the Python-based Spyder software (Afshin & Yas, 2026). If a solid object has an initial length L_0 at an initial temperature T_0 , then its temperature is increased by ΔT . The change in the object's length can be explained by the following equation (1).

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T \quad (1)$$

Based on equation (1), L_0 is the initial length of the object, α is the coefficient of linear expansion, and ΔT is the temperature change. After obtaining the increase in length due to heating using equation (1), the next step is to determine the object's final length after expansion. Length expansion in solids is a physical phenomenon that occurs as the material increases in temperature, thereby increasing the distance between particles (Su et al., 2026).

The change in length is directly proportional to the change in temperature, provided the temperature change is not too large. The final length of an object undergoing linear expansion can be calculated using equation (2).

$$L = L_0 + \Delta L \quad (2)$$

Based on equation (2), L is the final length after expansion, L_0 is the initial length of an object, and $\Delta L = L_0 \alpha \Delta T$ is the length calculated from equation (1). This equation is widely used in the analysis of basic physics and engineering. For most metallic or non-metallic materials, the expansion coefficient α is determined experimentally and can be found in the material properties table in Indonesian physics literature (Jebur et al., 2022). In general, the size of an object changes with its temperature. If an object's temperature increases, it will expand (Al-Hazmi et al., 2024). If a solid object has two dimensions (length and width) and is heated, both its length and width will expand, or in other words, the area of the solid object will expand.

The coefficient of area expansion, denoted by β , is the coefficient of expansion for area expansion. With length expansion, if the initial area is A_0 , the increase in area is ΔA , and

the temperature change is ΔT . Then, the coefficient of area expansion can be expressed by equation (3).

$$\beta = \frac{\Delta A}{A \Delta T} \quad (3)$$

From equation (3), the following equation is also obtained, equal to equation (4).

$$\Delta A = \beta A \Delta T \quad (4)$$

Based on equation (4), the $\Delta A = A_t - A_0$ equation becomes $A_t = A_0(1 + \beta \Delta T)$. The value of $\beta = 2\alpha$, so equation (4) can also be written as follows in equation (5).

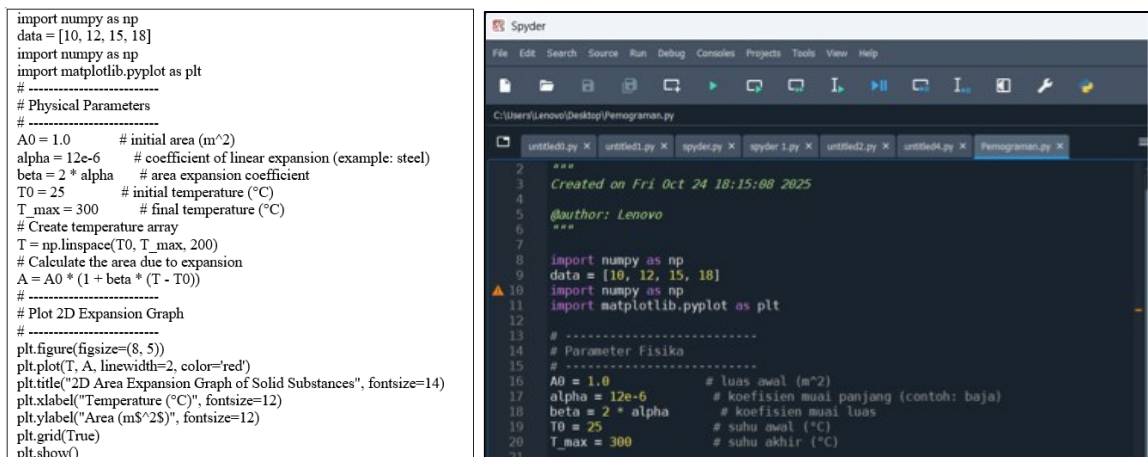
$$A_t = A_0 (1 + 2\alpha \Delta T) \quad (5)$$

Based on equation (5), A_t is the area of the object when heated, and A_0 is the initial area of the object. Furthermore, $\beta = 2\alpha$ is the coefficient of linear expansion ($/^{\circ}\text{C}$) and ΔT is the temperature change ($^{\circ}\text{C}$). The phenomenon of solid expansion has a major impact on engineering and everyday life. For example, gaps in railroad joints, window glass installation, and metal expansion on bridges are real-life applications of the concept of expansion that can be observed directly (Dove & Fang, 2016). However, research across various schools has shown that most students understand this phenomenon only by rote, rather than through a deep understanding of physics. As a result, when presented with contextual problems, they tend to make mistakes in their analysis (She et al., 2012). On the other hand, the expansion of solids is also suitable for digital simulation because the relationship is easy to understand. Using software such as Spyder, which is included in the Python environment, a teacher can create an expansion model based on available data, including the coefficient of linear expansion for various materials, such as steel, copper, aluminum, or brass (Hill et al., 2015). This model can help students understand how temperature changes affect length or volume numerically, not just through pictures. In addition, the use of Spyder in physics education provides students with the opportunity to analyze simple data, as scientists (Rais & Xuezhi, 2024).

METHOD

This study simulated the expansion of solids using Spyder, a Python-based software. The purpose of using Spyder in physics education is to facilitate understanding of physics concepts by illustrating them through simulations, images, and models. This software makes it easier for students to observe what is difficult to see with the naked eye, such as small objects under a microscope or rapid processes, thereby helping them better understand the material being taught (Lafuente et al., 2021). Spyder's role in simulating solid expansion is as an integrated development environment (IDE) for Python, allowing users to create numerical simulations of how the size of solid objects changes with increasing temperature. Using scientific libraries such as NumPy and Matplotlib, students can create models to predict changes in the length, volume, or shape of solid objects due to temperature variations and display the simulation results as graphs or animations (Rais & Xuezhi, 2024). Before starting the research, ensure that the laptop or computer has the Spyder application installed, along with supporting libraries such as Numpy, used to process numerical data, and Matplotlib, used to create 2D graphs. After that, to simulate the expansion of solids, the first step is to determine the initial length of the object (L_0) and the coefficient of linear expansion (α) of the material used. The expansion of solids can be calculated using equation (1). After obtaining the increase in length due to heating using equation (1), the next step is to determine the object's final length after expansion. Linear expansion in materials is a physical phenomenon that occurs when a substance experiences an increase in temperature, causing the distance between the particles within it to become greater. The final length of an object undergoing linear expansion can be

calculated using equation (2). Based on the mathematical equation for 2D solid expansion, the following implementation can be used in Spyder. To create a solid expansion graph, Python-based code is used and run through Spyder. The code includes important variables, such as area A_0 , linear expansion coefficient α , and temperature range ΔT , which are then used to calculate and display a graph. This presentation aims to provide students and readers with an understanding of the calculation process for creating expansion visualizations and to demonstrate how physics concepts can be combined with programming. In this way, students not only learn physics concepts, but also gain hands-on experience in applying programming logic. The code used in creating the expansion graph is shown in Figure 1.



```

import numpy as np
data = [10, 12, 15, 18]
import numpy as np
import matplotlib.pyplot as plt
# -----
# Physical Parameters
# -----
A0 = 1.0      # initial area (m^2)
alpha = 12e-6 # coefficient of linear expansion (example: steel)
beta = 2 * alpha # area expansion coefficient
T0 = 25      # initial temperature (°C)
T_max = 300  # final temperature (°C)
# Create temperature array
T = np.linspace(T0, T_max, 200)
# Calculate the area due to expansion
A = A0 * (1 + beta * (T - T0))
# -----
# Plot 2D Expansion Graph
# -----
plt.figure(figsize=(8, 5))
plt.plot(T, A, linewidth=2, color='red')
plt.title("2D Area Expansion Graph of Solid Substances", fontsize=14)
plt.xlabel("Temperature (°C)", fontsize=12)
plt.ylabel("Area (m$^2$)", fontsize=12)
plt.grid(True)
plt.show()

```

Figure 1. Program Code for 2D Solid Expansion in the Layer Editor of the Spyder Application

Based on Figure 1, the compiled code or the programming language for the 2D solid expansion is displayed in the Spyder application editor. The code has been successfully entered and systematically organized in the Spyder menu editor, allowing users to set algorithmic parameters for the physical variables involved, including the geometric parameters of the two-dimensional solid and the thermal expansion coefficient. The next step is to press the Run button in Spyder to execute all program instructions, resulting in a dynamic visualization of the two-dimensional expansion phenomenon.

RESULTS AND DISCUSSION

The 2D Solid Expansion Graph

To visualize the relationship between temperature changes and changes in the size of solid objects, a two-dimensional (2D) expansion graph is created using Spyder software. This graph shows the linear increase in area A_t as temperature rises ΔT according to the area expansion equation $A_t = A_0 (1 + 2\alpha\Delta T)$. From this graph, students can directly observe how increasing temperature affects the size of solid objects and understand that the expansion is linear. This visualization is expected to clarify the concept of expansion, which was previously understood only through formulas and theoretical explanations. The code used in creating the expansion graph is shown in Figure 2.

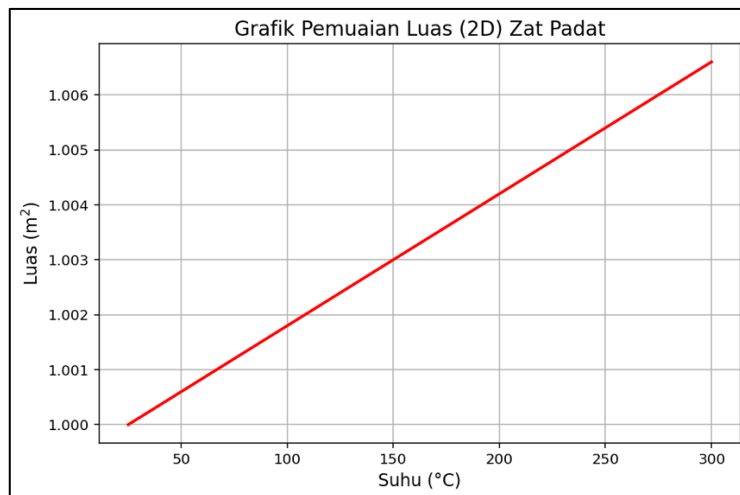


Figure 2. Results of the 2D Solid Expansion Graph

This study produced a two-dimensional (2D) solid-expansion graph using the Python-based Spyder software. The graph shows the relationship between the change in temperature (ΔT) and the change in solid area (A_t) as described by the equation. In the modeling test, the initial area (A_0) and linear expansion coefficient (α) of common metals such as aluminum and copper were used. The temperature range was 0-100°C to clearly observe changes in area (Martin et al., 2026). The graph shows that the expansion curve increases linearly with temperature, as expected for a solid's linear expansion. Aluminum, which has a higher coefficient of thermal expansion, shows a steeper line than steel. There is no difference in the shape of the curve, which shows that the mathematical model is consistent with the theory of expansion in solid materials (Najafi et al., 2026). This graph shows the increase in the size of a solid object as it heats, allowing one to observe how temperature directly affects its size. The expansion of solids generally occurs when the temperature is raised, as increased atomic kinetic energy increases the amplitude of atomic vibrations and the interatomic distance (Li et al., 2026). This causes the atoms to move apart, increasing the object's size. The results of this study are consistent with the theory that the coefficient of linear expansion plays an important role in determining the extent of size changes in a material. This study shows that continuous use of graphs and interactive visualization tools can improve students' understanding of mathematical concepts, critical thinking, and problem-solving skills. Visualization can help students connect abstract concepts with more tangible forms, allowing them to see and understand how variables interact directly (Az-zahra et al., 2024; Liu et al., 2026).

Results from using Python code in Spyder show that the expansion modeling process can be carried out in a simple, organized manner. This process helps students learn to think systematically, from identifying variables and entering physical equations to displaying results in graphical form (Binali et al., 2024; Fauza et al., 2025). The use of solid expansion graphs in Spyder has a very positive impact on learning. Graph visualization helps students clearly understand the relationship between temperature and size changes (Hernández et al., 2021). This exploratory learning helps students understand concepts through direct experience rather than just listening to teachers' explanations. Thus, the graphs can also help students improve their analytical thinking skills, such as reading graphs, interpreting line slopes, and connecting numbers to real phenomena. This aligns with the objectives of 21st-century physics education, which focus on critical thinking, problem-solving, and technological skills (Byrne et al., 2023). This experience adds value in learning by combining physics, mathematics, and technology into a single unit. The use of graphs in

learning not only helps illustrate mathematical relationships but also reinforces students' understanding of concepts. Students can see that $t = \Delta t$ increases are proportional to ΔT because the line is straight and has a positive slope. This helps reduce misunderstandings, such as the belief that expansion occurs exponentially or non-linearly within the normal temperature range.

The expansion of solids is evident in real-world objects such as railroad tracks, window glass, and metal joints. For technical glasses such as borosilicate, their expansion properties are modified to be very small, so that they do not break easily when subjected to sudden temperature changes. Glass with low expansion rates is often used in optical and electronic equipment that requires stable dimensional stability (Li et al., 2026; Yani et al., 2021). As the temperature increases, these objects will expand and change size. If these changes are not properly calculated or addressed, they can cause structural problems, such as cracks or deformation of the object. Therefore, engineers typically incorporate tolerance margins into designs to account for expansion (Dong et al., 2026). Understanding these expansion graphs can help students grasp the rationale behind such engineering designs. Research on physics education emphasizes that the ability to read graphs is an important foundation for understanding abstract physics concepts (Bates et al., 2024). Two-dimensional graphs of solid expansion also help students connect physics theory to their daily experiences. Examples such as gaps in railroad tracks, window glass installation, and metal joints on bridges can be explained more rationally through expansion graphs. Knowing that temperature changes can cause objects to expand or contract helps students realize how important it is to calculate expansion in everyday life (Kadan-Tabaja & Yerushalmy, 2024). Although the graph results are consistent with theory, this simulation still has several weaknesses. The model used assumes that the coefficient of expansion remains unchanged and that the material has the same structure throughout and is uniform in all directions. This assumption is no longer valid at very high temperatures or near the melting point, as the material's crystal structure can change under these conditions. However, in high school education, where temperatures are not too high, this approach is sufficient.

CONCLUSION

Based on the discussion of using two-dimensional (2D) solid expansion graphs in physics learning with the Spyder software, it can be concluded that technology-based media have a significant positive impact on students' understanding. Visualizing graphs of the relationship between temperature changes and changes in the size of solid objects makes the previously abstract concept of expansion easier to understand in real terms. Using the Spyder application can help students directly observe how an object's size changes according to the area expansion equation. Through these graphs, students can directly see the relationship between temperature and area, understand differences in material expansion based on their coefficients of expansion, and relate this concept to everyday events. Using this method, learning is not just about memorizing formulas. It is about a deeper understanding of the concept. In addition, a technology-based learning approach can help develop 21st-century skills such as critical thinking, information analysis, and technology use. Students can also be motivated to independently explore data, perform simulations, and make scientific conclusions. This aligns with student-centered, project-based learning methods that emphasize active student involvement in the learning process. However, research also shows that the use of technology such as Spyder still faces several problems, including insufficient facilities, insufficient teacher training, and students' readiness for independent learning. Therefore, adequate facilities, training in

technological skills, and well-organized learning designs are needed to ensure the effective use of digital media. In general, the use of solid-substance expansion graphs in Spyder has been shown to help students better understand concepts, improve learning, and make physics material more interesting and relevant to everyday life. This innovation is expected to improve the quality of physics learning in schools.

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