

Exploration of Thermodynamics Concept of Madura Klampar Written Batik: Integration of Culture and STEAM-Based Education

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Article Info	Abstract
Article history: Received: February 2, 2025 Accepted: March 3, 2025 Published: March 29, 2025 Keywords: Culture <i>Klampar Batik</i> STEAM Thermodynamic This article is licensed under a creative commons attribution-share alike 4.0 international license © 2025 Jurnal ilmiah Pendidikan Fisika	This research explores the concept of thermodynamics in making Klampar Madura batik, integrated with culture and education based on STEAM (Science, Technology, Engineering, Art, and Mathematics). Klampar batik, has a manufacturing process that involves thermodynamic concepts, such as changes in form and heat transfer. Thermodynamics is often considered an abstract and difficult subject for students to understand. The STEAM education approach offers a more engaging and applicable learning method, making thermodynamic concepts easier to grasp as they become more contextual. The research method used is descriptive qualitative with a cultural studies approach. Data collection techniques were conducted through interviews, observation, documentation, and literature study. The research results reveal that making Klampar batik involves the concept of thermodynamics at the stages of melting wax, fixation, and drying. Integration of physics concepts with culture and STEAM education, which includes Science (thermodynamics), Technology (canting design), Engineering (fabric, biron wax, canting), Arts (motifs), and Mathematics (thermodynamics in the fixation process). Through the STEAM cultural and educational approach, the batik process is a means to create works of art and preserve culture with a cross-disciplinary, knowledge-based approach.
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INTRODUCTION

Batik is an Indonesian cultural heritage estimated to have developed since the 16th century (Prasetyaningrum, 2020; Raya et al., 2021). Batik designs have symbolic meanings that reflect the local community's culture, making them the hallmark of batik from the region (Indarti et al., 2020; Minarno et al., 2024). Almost all areas of Indonesia have distinctive batik motifs, such as Klampar hand-written batik from Pamekasan (Syarifudin et al., 2024). The unique characteristics of the full motif and striking colors in Klampar hand-written batik are irreplaceable (Sumartinah et al., 2023). The striking colors and full motifs in Klampar hand-written batik depend highly on the manufacturing process (Wicaksana et al., 2021). The making of Klampar handmade batik has unique characteristics, namely using biron wax that can be used repeatedly, repeated dyeing to obtain striking colors, and layered batik up to three times to produce a complete motif (Prasetyaningrum, 2020). The uniqueness and characteristics of making Klampar handmade batik cannot be separated from the role of physics concepts that work at every stage (Nikmah & Deta, 2023).

The concept of thermodynamics is the most dominant physics concept in making Klampar handmade batik. Thermodynamics is a branch of physics that studies the relationship between heat and changes in the form of energy (Mahardika et al., 2023; Wahyu et al., 2023; Astuti et al., 2024; Shofia et al., 2024). The concept of thermodynamics plays an important role in various stages, such as melting the biron wax, the drying process, and the fixation/staining process (Wahyu et al., 2023). Melting the biron wax requires proper heating so that the Biron wax can be applied correctly without damaging the fabric; the fixation process requires specific temperature control so that the biron wax can be released from the batik cloth (Safitri et al., 2023). The concept of thermodynamics has an important role in regulating temperature and energy transfer to produce quality batik. In the world of education, thermodynamics is one of the important materials in the physics curriculum in high school (Sunardi, 2021; Zein et al., 2023). However, many students still have difficulty understanding thermodynamic material due to abstract concepts and lack of context, so students often misinterpret the material taught (Agusstiawan et al., 2021; Soprihatin & Haqiqi, 2021; Purwanti, 2023; Fauzi, 2024). In addition, the learning approach using the lecture method tends to be boring, thus reducing students' interest in learning. Therefore, a more contextualized approach is needed to make students more interested in learning thermodynamics (Rahmat et al., 2023).

Culturally integrated STEAM learning provides students with a contextual, relevant, and meaningful learning experience. Subsequently, learning a culturally integrated STEAM (*Science, Technology, Engineering, Art, and Mathematics*) based approach is very suitable for use in this material because it connects abstract concepts with culture from the local area, thus encouraging students to think creatively in solving problems integrating theory with practice in everyday life (Kurniawan et al., 2024; Lestari, 2021). In addition, through the STEAM approach, students can apply the knowledge they learn directly so that their understanding becomes deeper (Chintya et al., 2024; Aprianti et al., 2023; Triwahyuningtyas et al., 2021). STEAM-based approach can improve students' collaboration and creativity skills and direct students in mastering various fields in the era of skills 21 (Mansur et al., 2022; Azzahra, 2024). Furthermore, learners can enhance their logical reasoning and gain extensive opportunities to develop and refine their thinking skills (Utaminingsih et al., 2023).

The concept of thermodynamics in the making of Klampar batik Madura not only broadens the understanding of the relationship between science and culture but also provides a more relevant and interesting learning approach for students (Zahro et al., 2023). Based on the description above, batik can be a means of helping students understand thermodynamics, which is often considered difficult due to the lack of real application and boring lecture methods. Still, there has been no specific research that examines the concept of thermodynamics, cultural integration, and STEAM education in the process of making Klampar batik. Based on the description above, the researcher aims to explore the concept of thermodynamics in making Madura Klampar batik integrated with culture and STEAM-based education.

METHODS

The research method used in this research is the descriptive qualitative method. Descriptive qualitative is a research method used to describe in depth and detail a particular phenomenon, event, or condition (Hasibuan et al., 2022). In this research, the approach used is a cultural study approach. The ethnographic approach aims to analyze and describe the thermodynamics that exist in making Klampar handmade batik (Ramayanti et al., 2019). This research consists of five women and two men working as batik craftsmen at CV Bintang Abadi, Pamekasan. The sample selection technique used was purposive

sampling (Lenaini, 2021), with consideration of the duration of experience as a Klampar batik craftsman, skills in batik techniques, and the level of difficulty in making batik motifs. The following is Figure 1 of the research flow used in this study.

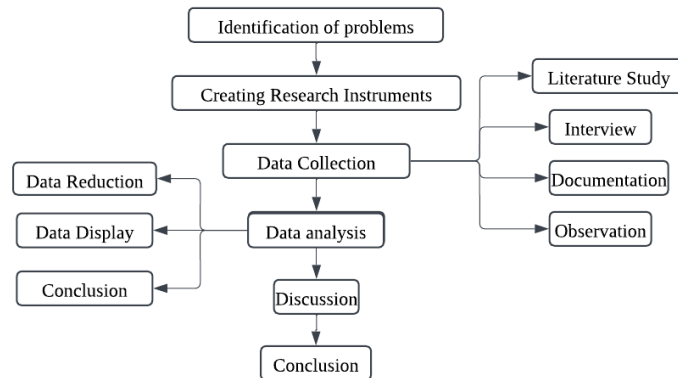


Figure 1 Research flow chart

The initial stage of research begins with identifying relevant problems that need to be resolved. After the problem is identified, the researcher designs the research instrument used to collect data; this research instrument is an interview guide and observation sheet (Anto et al., 2024). Data collection techniques were carried out through literature studies, interviews, documentation, and observations at CV. Bintang Abadi Pamekasan Regency Madura (Waruwu et al., 2023). Literature studies were conducted to strengthen the data obtained. Interviews were conducted to obtain data that researchers could not observe directly. In addition, interviews were conducted to determine the effect between the variables studied. Documentation is done to facilitate the depiction of the concepts of temperature and heat in making Klampar batik.

The observation was done by observing and looking directly at making Klampar hand-written batik at CV. Bintang Abadi. The variables studied in this study are the process of making Klampar hand-written batik, which includes biron wax, color temperature, biron wax heating process, time, type of fabric, and drying. The data analysis process is carried out in three stages: data reduction, data presentation, and conclusions (Miles & Huberman, 1994). Data reduction is done by summarizing, filtering, comparing, and selecting important data from interviews, observations, documentation, and literature studies. The selected data is then presented as descriptive text, tables, and diagrams and interpreted to conclude. Furthermore, discussions are held with experts to obtain more comprehensive conclusions.

RESULTS AND DISCUSSION

UNESCO recognized Indonesian batik as a world intangible cultural heritage in 2009 (Nurjanah et al., 2021). Written batik, especially Klampar written batik, Madura, has its uniqueness with distinctive motifs and striking colors that reflect local cultural values (Wahyuningsih et al., 2024). The making of Klampar hand-drawn batik is genderless; both men and women are involved in the process. Over time, the craftsmen have become more adept at creating intricate batik motifs without relying on patterns, reflecting a high level of mastery of batik techniques (Wibisono et al., 2020).

The hand-written batik motifs produced by Klampar Village craftsmen are very diverse and continue to develop in line with market demand but still maintain their characteristics, such as striking colors and full motifs without empty spaces. The motifs reflect the attributes of the Madurese people, who are tenacious and hardworking. The making process is based on the concept and philosophy of the surrounding environment, reflecting the local

cultural identity. Cultural heritage, such as written batik, continues to evolve according to social, economic, and environmental changes (Prasetyaningrum, 2020).

The Making Process of Klampar Batik

The making of Klampar hand-drawn batik can be analyzed from a thermodynamic perspective to understand the energy and heat transfer changes during each manufacturing stage. The concept of thermodynamics explains how energy is used, absorbed, and released (Ranakusuma et al., 2021). In this process, the principles of physics affect the outcome of motifs and fabric quality. In the process of making Klampar batik, physics plays an important role in the batik making, fixation, and drying stages. The making of Klampar handmade batik is carried out in quite complicated stages to produce quality batik. The stages in making Klampar batik can be seen in Figure 2.

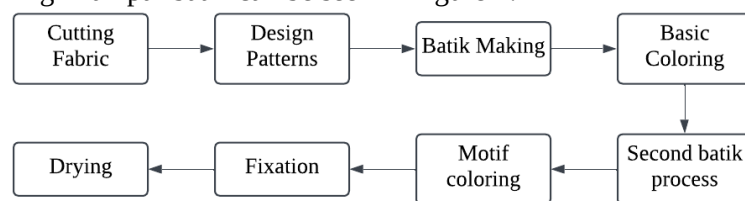


Figure 2 The process of Batik Production

a. Cutting Fabric

Cutting Klampar hand-written batik cloth usually varies according to the buyer's request. Unlike stamped or printed batik, which has a standard size (Syamsuddin & Amir, 2021). However, the average cutting of Klampar handmade batik is 220 cm-240 cm long and 100 cm-110 cm wide.

b. Designing Patterns

The process of designing batik is an essential stage in batik-making (Purnomo et al., 2022). As experience grows, craftsmen can create complex batik motifs without needing patterns.

c. Batik Making

Batik Making (*Membatik*) is the process of stretching biron wax on the fabric according to the pattern that has been made. The process of stretching biron wax is carried out by craftsmen using *canting* to apply biron wax that has been heated to melt, following the pattern that has been designed (Sugiyardi, 2023). The phenomenon of heat-induced melting of biron wax is an influence of thermodynamic principles. At this stage, the melting process of the biron wax is very important because if the wax does not melt properly, it will be difficult to apply to the batik cloth, or even the wax will not stick to the surface of the cloth.

d. Basic Coloring

In the making of written batik, after the biron wax process, the next stage is to apply color to the fabric. One of the most commonly used coloring techniques is the dyeing technique. The dyeing technique is done by immersing the entire or part of the fabric into a warm dye solution. This technique is generally used to provide a basic color on the fabric or to color large areas (Syamsuddin & Amir, 2021).

e. Second Batik Process

At this stage, the melted biron wax is reapplied to the fabric to cover certain parts of the motif that do not want to be exposed to color in the following dyeing process (Ulfah,

2024). Protecting certain patterns to stay true to the original design during the dyeing process. In this process thermodynamics also plays a central role in melting the biron wax.

f. Motif Coloring

This coloring determines the background color or other elements that are not covered by the biron wax (Ulfah, 2024). Dip all parts of the fabric into the base dye solution. Adjust the dipping time to achieve the desired color intensity.

g. Fixation/*Pelorodan*

One of the important stages in the batik-making process, which aims to remove the biron wax layer, is fixation/ *pelorodan*. The boiling time varies depending on the type of dye and the type of fabric used in general. The duration of batik boiling usually ranges from 15-30 minutes (Putri et al., 2022). This process utilizes thermodynamic principles to transform the biron wax from solid to liquid. In addition, conduction plays a role in transferring heat from the heat source (fire) to water, while convection plays a role in distributing heat evenly throughout the water (Cahyaningtyas, R., & Putra, 2020).

h. Drying

The last stage of the batik-making process is drying (Putri et al., 2022). The drying process of Klampar Madura handmade batik still relies on traditional drying methods that utilize solar heat and airflow. In this context, the concept of thermodynamics plays a role through radiation heat transfer, which does not require an intermediary medium. The batik cloth absorbs Thermal energy from sunlight, causing the wet cloth to dry. Temperature, surface area, properties, and type of fabric material influence this process (Suharli et al., 2024).

Study on the Integration of Culture and STEAM Education

The principles of thermodynamics influence the stages in making Klampar batik. Thermodynamics is a branch of physics that studies heat and energy changes (Maryana et al., 2023). Naturally, heat moves from high-temperature (hot) material to lower-temperature (cold) material (Zu & Li, 2000). Temperature is a measure of how cold or hot an object is, and the higher the temperature, the more energy the particles that make up the object move (Utama, 2022). Meanwhile, heat is energy moving from objects with high temperatures to those with lower temperatures. Heat transfer can occur through conduction, convection, and radiation (Salo et al., 2023).

When the biron wax is heated, the heat received by the batik wax causes the batik wax to change shape into liquid. The optimal temperature is also important to produce an even and long-lasting color in the fixation process. If the temperature is too low, the chemical reaction will take place slowly, and the color will not stick perfectly to the making of Klampar batik (Safitri et al., 2023). Conversely, if the temperature is too high, the fabric fibers can be damaged, and the color will fade. After dyeing, the cloth is aerated or dried in the sun to remove the remnants of the dye and evaporate the water (Syaharani et al., 2024). This evaporation process requires heat. Heat transfer from the environment to the fabric causes the water to evaporate and the color to become more fade-resistant. Thus, thermodynamics is an essential factor that must be properly controlled in making Klampar batik.

The important role of thermodynamics in the process of making Klampar batik can be utilized in STEAM-based physics learning (Widarti & Roshayanti, 2021). STEAM education is very relevant in making Klampar batik, because students can learn practically about the interaction between science (thermodynamics), technology (*canting*), engineering (selection of materials such as biron wax, fabric, and *canting* materials), art (motif design), and mathematics (essential aspects of the fixation process). Through STEAM-based learning, students can better understand physics concepts in real life and appreciate cultural arts related to the process. The following are the results of the analysis related to the concept of thermodynamics in a culture-based approach and STEAM education:

Science

1) Batik Making

The phenomenon of Biron wax melting due to heat can be explained using the concepts of thermodynamics and heat transfer. When Biron wax is heated, the thermal energy it absorbs causes its temperature to rise until it reaches its melting point. Figure 3 schematically represents the influence of thermodynamic concepts.



Figure 3 Biron wax melting process

$$Q = mc\Delta T + mL$$

Description:

Q = total heat (joules)

m = the biron wax mass (kg)

c = specific heat of wax (J/kg·°C)

ΔT = temperature change (°C atau K)

L = latent heat of wax melting J/kg)

When a candle receives heat, the energy is used first to increase the temperature of the candle by ($mc\Delta T$). Once the temperature of the wax reaches the melting point, additional energy (mL) is used to change the phase of the wax from solid to liquid. Meanwhile, the melting rate of wax can be formulated by:

$$\frac{dm}{dt} = \frac{P}{mL}$$

Description:

$\frac{dm}{dt}$ = wax mass change rate (kg/s)

P = heat power received by the candle (W or J/s)

mL = latent heat of wax melting (J/kg)

Based on the formula above, it can be concluded that the greater the P heat power received by the candle (W or $\frac{J}{s}$), the faster the wax melts by $\frac{dm}{dt}$.

2) Fixation

The stage in making Klampar handmade batik aims to remove the biron wax layer from the fabric after the coloring process is complete. This technique is done by boiling the batik cloth in hot water so the biron wax melts and detaches from the fabric fibers. This process is important for removing the iron wax and ensures that the batik pattern looks clear and neat. The thermodynamic process involved in the fixation process is illustrated in Figure 4.



Figure 4 Fixation process

$$Q = mc\Delta T$$

Description

Q = heat required

m = water mass

c = specific heat of water (4186 J/kg°C)

ΔT = is the change in water temperature

Boiling the fabric increases the temperature of the biron wax until it passes its melting point through the intermediary of water so that the biron wax changes from solid to liquid. Then, the conduction process plays a role in transferring heat from the heat source (fire) to water, while convection plays a role in distributing heat evenly throughout the water (Cahyaningtyas, r., & putra, 2020). Heat transfer is very important in the water fixation/boiling process to ensure the color sticks well and the motif looks beautiful. In addition, hot water in this process helps dissolve the dye by opening the pores of the fabric (Pujilestari, 2017).

3) Drying

The drying process of Klampar Madura hand-written batik still relies on traditional drying methods that utilize solar heat and airflow. In this context, thermodynamics plays a central role in the batik drying process. Figure 5 shows the drying process of batik fabric.

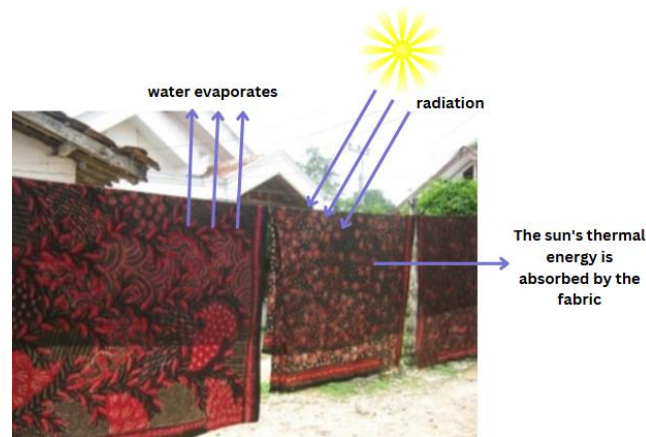


Figure 5 Drying process

Drying evaporates liquid substances in materials with heat through convection, conduction, radiation, or electromagnetic waves. This process involves reducing the moisture of the material by heating the air or increasing the pressure so that water vapor moves from the material to the air (Anam, 2021). Batik drying uses sunlight (drying) to reduce the moisture content of the fabric through radiation heat transfer, which does not require an intermediary medium. The batik cloth absorbs Thermal energy from sunlight, causing the wet cloth to dry. Temperature, surface area, properties, and type of fabric material influence this process (Suharli et al., 2024).

Technology

Canting is designed with a distinctive shape due to its specific function in the batik process. The *canting* design refers to the need to apply hot wax precisely. The *canting* handle is made lighter with a length of 20 cm and a diameter of 1.5 cm, or designed according to the ratio of a woman's hand to make it easier for the hand to hold the tool for a long time without feeling tired. This handle (*gagang*) keeps the user's hand away from the heat of the molten wax. The prong on the *canting* is the part that channels the molten wax onto the fabric with a diameter of 0.6 mm. *Nyamplung* is a place to hold hot wax, so it is designed to hold enough wax to make continuous motifs without having to refill it frequently (Siswati et al., 2024). A comparison between *canting* and human hands can be seen in Figure 6.

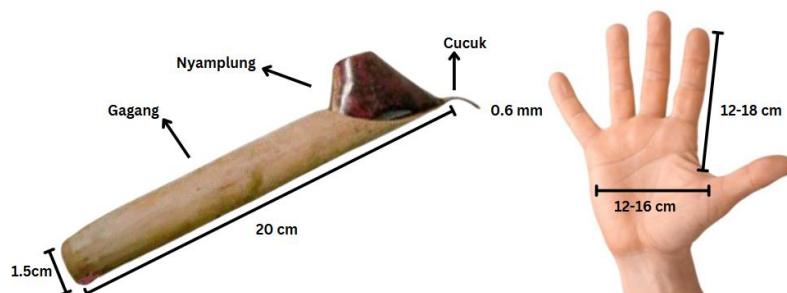


Figure 6 Comparison of hand and canting

Engineering

1) Biron wax

Batik uses batik wax on a cloth to be a color resist or repellent (Wati & Kusumastuti, 2022). The batik wax used in making Klampar batik is biron wax. Biron wax is made from a combination of gondorukem, kote, paraffin, kendal, used wax, coconut oil. When

heated, this wax will melt perfectly at 60°C- 100°C; Biron wax melts faster than other types of batik wax. This type of wax has a density of 0.90-0.95 g/cm³ (Haerudin & Atika, 2018). Biron wax can also be used repeatedly, which is very energy efficient, as seen in Figure 7.



Figure 7 Biron wax

2) Fabric

All fabrics can be made of batik except plastic-based fabrics such as polyester. In making Klampar handmade batik, the fabric commonly used is cotton (*mori*). This is because the nature of cotton cloth is easily adaptable to changes in temperature, making it easier to process in batik-making (Rumiyati et al., 2023). Table 1 is a comparison of cotton (*mori*) fabric with polyester fabric:

Table 1 Comparison of Cotton (*Mori*) Fabric with Polyester Fabric

Aspects	Cotton Fabric (<i>mori</i>)	Polyester Fabric
Basic materials	Cotton fiber	Synthetic fibers from plastic polymers
Absorbency	able to absorb liquids and colors well	less good at absorbing liquids and colorants
Temperature Resistance	Heat resistant up to 100°C	Melts at 65°C-70°C
Batik Making Process	Suitable for batik because it easily absorbs wax and dye	Not suitable for batik because waxes and dyes are difficult to stick to, and will melt during the fixation process
Color Softness	Provides bright and sharp color results	Color is less sharp and not long lasting when dyed

3) *Canting*

Canting is a traditional tool used in the batik process to inscribe biron wax on the cloth. *Canting* consists of several main parts: the handle, *nyamplung* (liquid wax container), and *cucuk* (small pipe as the wax outlet). *Canting* is generally made of wood or bamboo for the handle, and copper for the *nyamplung* and *cucuk*. Copper is chosen because it can conduct heat well so that the night remains liquid and flows easily when applied to the fabric. Figure 8 shows the process of making batik using *canting* (*mencanting*).



Figure 8 *Mencanting*

The *canting* used must be able to distribute heat to keep the wax liquid and easily applied to the fabric (Sulistiani et al., 2022). *Canting* has a metal part that is used to store the wax. When the biron wax is heated, heat energy from the source is transferred through conduction to the *canting* metal, allowing the wax to melt and be ready for use. The metal often used to make *canting* is copper because it has properties as an excellent conductor of heat and electricity (Sudarto, 2020). The following is Table 2 of metal advantages (Chen et al., 2024) which is why it is used as a *canting*.

Table 2 *Copper Advantages*

Criteria	Copper Metal	Reason
Material	Copper	Strong, durable, malleable
Thermal Conductivity	High (398 W/m-K)	Heats up faster, keeping the wax liquid
Boiling point	About 2.562°C	High-temperature-resistant copper
Melting point	About 1.085°C	Copper has a lower melting point, making it easily suitable for melting wax.
Corrosion Resistance	Moderately resistant to corrosion	Although copper can rust, it is relatively more durable.

Art

Batik Klampar is one of the typical types of batik from Pamekasan Regency, Madura, which is famous for its unique motifs and deep cultural philosophy. This batik is known for its striking and contrasting color combinations, such as red, blue, yellow, and green. An example of Klampar batik motif can be seen in Figure 9.



Figure 9 Finished batik cloth

The complex process of making batik results in higher artistic value as more biron wax is required for detailed motifs. The temperature of the biron wax affects the quality of the motif. The temperature of the biron wax significantly affects the smoothness, sharpness, and durability of the batik pattern. At very high temperatures ($>120^{\circ}\text{C}$), the wax is too liquid, difficult to control, absorbs excessively into the fabric, and causes blurred motifs and lack of precision. The optimum temperature ($60^{\circ}\text{C} - 80^{\circ}\text{C}$) is the best condition, where the wax is liquid enough to form smooth, sharp, and consistent lines and protect the fabric from dyes. If the temperature is too low ($<60^{\circ}\text{C}$), the wax becomes thick, difficult to flow, and results in rough and uneven lines. At very low temperatures, the wax starts to freeze, causing the motif to be disjointed or not even formed. Therefore, keeping the wax temperature stable is very important so that the batik motif remains precise, aesthetic, and according to the desired pattern. Klampar batik is known for its characteristic bright colors and intact motifs that reflect the local culture of Pamekasan, Madura, following its classification in Table 3.

Table 3 Uniqueness of Klampar Batik

Aspects	Characteristic (Uniqueness)
Color	The dominance of bright and bold colors such as red, yellow, blue, and green reflects cheerfulness and courage.
Motive	Traditional Madura motifs such as Hong birds, flowers, and plants with intricate details.
Characteristics	The bold and contrasting lines with a mix of striking colors show Madura's strong character.

Mathematic

As explained in the previous sections, thermodynamics plays an important role in the batik-making process. The fixation process, which is the final stage of the whole series, requires high temperatures to boil the batik cloth and melt the Biron wax. Therefore, Table 4 classifies the thermodynamic aspects that influence the fixation process.

Table 4 Important aspects of thermodynamics in the fixation process

Aspects	Explanation
Fixation Temperature	80°C - 100°C (depending on fabric type and color).
Time	Usually 30 minutes, depending on the type of ingredients used.
Results	The colors are sharp, long-lasting, and do not fade even when washed.

Integrating the STEAM concept in learning makes Klampar Batik provide a holistic approach to understanding the batik-making process not only from an artistic point of view but also from the five aspects of STEAM learning. This approach can be applied in the world of education to introduce students to physics through culture-based activities. In this way, learning becomes more contextual, interesting, and applicable in real life.

CONCLUSION

Klampar's written batik from Madura is unique in its motifs and colors, which reflect the culture of the Pamekasan community, Madura. This research explores the concept of thermodynamics in making Klampar batik by integrating cultural aspects and STEAM-based educational approaches. The process of batik making, from melting the biron wax and coloring to fixation, shows the principles of thermodynamics, such as heat transfer through conduction, convection, and radiation. This proves that physics concepts are theoretical and have direct applications in daily cultural practices. The STEAM education approach in physics learning can effectively improve students' understanding of thermodynamics. Connecting science with batik art rooted in local culture allows students to learn more contextually, creatively, and collaboratively. It also helps develop 21st-century skills, such as problem-solving and innovation. Culture-based STEAM education can be a means to enhance students' appreciation of local heritage. Connecting science with culture strengthens academic understanding and builds identity and pride in national culture. With this approach, physics learning can become more meaningful as an abstract theory and part of everyday life rich in cultural values and innovation. While cotton and polyester fabrics have been described, there is still no in-depth analysis of the effects of fixation on other types of fabrics. Further understanding of how different fabrics respond to the fixation process and the optimal temperature (80°C-100°C), which can vary depending on the type of wax and dye, is needed. Further research is expected to examine these factors to optimize fixation on various fabrics and dyes. In addition, it is necessary to develop a STEAM-based learning module that integrates the concept of thermodynamics

with the batik process and tests its effectiveness in improving students' understanding in schools.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, HAD & CS; methodology, ID; formal analysis, ID; data collection, ID; writing preparation of the original draft, ID; editing and revision, HAD & CS; supervision, HDA.

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