

Designing Colorful Sustainable Toys for Babies: A Sustainable Design Approach

Devanny Gumulya*^{ID}, Casey Gunawan^{ID}

School of Design, Pelita Harapan University, Tangerang, Banten 15811, Indonesia

Corresponding Author Email: devanny.gumulya@uph.edu



<https://doi.org/10.18280/ijdne.180311>

ABSTRACT

Received: 27 February 2023

Accepted: 31 May 2023

Keywords:

sustainable toy, soft toy design, natural dye, environmentally friendly

Play is an important aspect of childhood. It is important to introduce sustainability concepts early in life by letting children play with sustainable toys since they will become tomorrow's adults. Unfortunately, options for sustainable toys are currently limited, often made from materials like bamboo and wood which lack the colorful sensory stimulation important for children's cognitive development. This study aims to create sustainable toys that are colorful and made with natural dyes to provide the right sensory stimulation for babies aged 0-6 months. The study employs a combination of experimental and design methodologies. Experimentations were performed to determine the most suitable plants that offer a broad spectrum of hues, the best organic fabrics, and optimal dyeing techniques. Meanwhile, design process is implemented in creating two soft toys that provide a range of sensory stimulations, including visual, auditory, and tactile experiences. Based on the research process, the study proposes a sustainable toy design methodology that involves three key stages: experimentation, design, and testing. The methodology is a structured and systematic approach to create sustainable toys with experimentation phase involves researching and identifying the best materials and procedures for preparing the sustainable materials, while the design phase focuses on implementing these materials into creating soft toys that provide the necessary sensory stimulations. Finally, the testing phase involves evaluating the effectiveness of the toys through user testing and feedback. By integrating the principles of natural dyeing into the toy design process, the methodology provides practical guidance for future designers who aspire to create environmentally sustainable toys that are not only attractive but also environmentally friendly.

1. INTRODUCTION

Play is a defining characteristic of childhood and is crucial for children's overall health, growth, development, and education. Children spend a significant amount of time playing with toys, making educational and recreational toys a highly sought after and profitable market. In fact, toy sales globally reached a total of \$36.7 billion in 2022 [1].

Although toys are important for children's cognitive and social-emotional development, children quickly grow out of their toys due to their constant change in interests. Most toys have an average lifespan of only six months, leading to a short life cycle for the toys [2]. Furthermore, toys made of plastic are often not easily recyclable because of the difficulty in separating the electronic parts.

Given the size of the toy industry and the rising concern plastic pollution in the industry of kid's toy, in 2022 a market research survey was conducted to 2,800 households with children aged 0-11 in Germany, Italy, France, China, Spain, the United Kingdom, and the United States. The study discovered that the majority of respondents considered toys, along with clothing and food, to be one of the most important categories in terms of sustainability [3].

For global consumers the use of sustainable materials in baby products has become increasingly important in recent years as society strives towards a more sustainable and conscious future [4]. Not only do sustainable materials offer

numerous environmental benefits, but they also have a direct impact on the health and well-being of children [5]. By choosing products made from sustainable materials, parents can ensure that their children are surrounded by safe, non-toxic, and environmentally responsible products [6].

Sustainable materials that are commonly used for toys are wood and bamboo. Despite being made from natural materials, sustainable toys made from bamboo and wood. They lack the color that is important for children's cognitive development [7]. Colors play a vital role in children's cognitive development as they help to stimulate their imagination and creativity. Bright, bold colors can also aid in developing their visual perception and enhance their memory. In comparison, toys made from bamboo and wood lack vibrant colors and are usually limited to natural hues. This can limit the stimulation of children's imagination and hinder their overall cognitive and social emotional development [8]. Furthermore, the absence of different colors can also make these toys less appealing to children and potentially discourage them from playing with them.

Despite the importance of color in children's cognitive development and the growing trend towards sustainable toys, there has been limited research examining the application of natural dyes in the development of children's toys. The current body of research primarily focuses on the materials and sustainability aspects of these toys [3, 6, 9], but there is a significant gap in the literature regarding the potential impact

of using natural dyes to enhance their visual appeal and cognitive benefits for children. As such, there is a need for further investigation into the use of natural dyes in the development of children's toys and their potential benefits for children's cognitive development. As a result, the research raises the research question of how we might create a sustainable toy that is colorful with natural dye? The objective of this study is to demonstrate experimentally that sustainable toys can be made colorful.

2. LITERATURE REVIEW

Natural dyes/colorants obtained from flora and fauna are thought to be safe due to they are proven to be nontoxic, non-carcinogenicity and biodegradable [10]. The study will concentrate on extracting dye from plants because previous research has found that it is better to extracting dye from animals for a variety of reasons [10-12]:

- **Sustainability:** Plants can be grown and harvested repeatedly, whereas animals need to be killed to obtain their natural dyes.
- **Cruelty-free:** The extraction of natural dyes from animals involves killing or harm to the animal, whereas plant-based dyes do not harm any living creatures.
- **Availability:** There are many more plants that can be used as a source of natural dyes compared to animals, making plant-based dyes more readily available.
- **Health and Safety:** Some animal-based dyes can contain harmful chemicals or pathogens that can be harmful to humans, whereas plant-based dyes are generally considered safer.
- **Environmental impact:** The production of animal-based dyes often generates waste and pollution, whereas the production of plant-based dyes is generally less harmful to the environment.

2.1 Materials and methods for natural dye










Natural dyes are generally extracted from the roots, stems, leaves, flowers, and fruits of various plants. The study compiles all plants that have previously been tested and proven to successfully produce bright colors.

2.2 Extracting natural dye

After compiling the natural dye sources, the authors proceeded to investigate the fabric dyeing process using plant-based dyes. The study findings revealed that this process generally consists of six key steps [10, 11, 13]:

- 1) **Collection of plant material:** The plant material (such as leaves, stems, flowers, roots, or bark) is collected and dried. Plants that can be source of dye can be seen on Table 1.
- 2) **Preparation of the dye bath:** The plant material is chopped, crushed, or ground into small pieces and then boiled in water to create a dye bath. A mordant is a substance that is used in the natural dyeing process to improve the color fastness and intensity of the dye. The dye bath can be modified with the addition of mordants or other substances to improve the colorfastness and intensity of the dye. The previous research on extracting natural dye can be seen on Table 2.

Table 1. Plants source of natural dye

Parts of Plants or Fruits	Picture	Dyes Content
avocado skins		chlorophyll and anthocyanin type cyanidin 3-o-glucoside
avocado pits		proanthocyanidin and tannin
mangosteen skins		anthocyanins (cyanidin-3-sophoroside), and procyanidin
red cabbage		anthocyanins (cyanidin-3-diglucoside-5-glucoside (80%) and cyanidin 3, 5 diglucoside (20%))
turmeric		curcumin
spinach		chlorophyll
suji leaves		chlorophyll
onion skins		quercetin and glucoside derivatives (quercetin-4'-glycoside and quercetin 3, 4'-diglucoside)
butterfly pea flowers		antosianin, delphinidin

- 3) **Fabric preparation:** To avoid interferences during the dyeing process, the fabric should be washed before natural dyeing to remove any residual chemicals, dirt, or oils. Natural dyes require a clean surface to effectively bond with the fabric fibers and produce long-lasting color. Contaminants on the fabric can also have an impact on the color outcome and cause uneven dyeing. Furthermore, washing the fabric before dyeing helps to ensure that any residue left on the fabric during the manufacturing process does not affect the color.
- 4) **Mordanting:** a preparatory step before the actual dyeing process in natural dyeing. It is done to enhance the colorfastness and permanence of the dye on the fabric or material. The mordant acts as a binding agent between the dye and the fibers, improving the dye's absorption and adherence to the fabric. There are different types of mordants that can be used in natural dyeing. Some of the commonly used mordants include alum, iron, copper, tin, and chrome. Potassium aluminum sulfate is the most frequently used mordant for protein and cellulose fibers and fabrics. Other types of mordants include biomordants, which are natural substances derived from plant extracts and can be used

as alternatives to metallic mordants. The type of mordant used depends on the type of fiber, the desired color, and the dyeing method.

- 5) **Dyeing:** The fabric or material to be dyed is immersed in the dye bath and left to soak for a specified period of time. The length of time and temperature will depend on the type of plant material used and the desired color.
- 6) **Rinsing:** The fabric or material is removed from the dye bath and rinsed to remove any excess dye.
- 7) **Drying:** The fabric or material is dried and may be washed or treated with a fixative to improve color fastness.

The exact process may vary depending on the type of plant material used, the desired color, and the type of fabric or material to be dyed. However, the basic steps of preparing a dye bath, dyeing the material, rinsing, and drying remain the same.

To be environmentally conscious during the natural dyeing process there is a growing trend to use bio-mordants as alternatives to metal mordants. A bio-mordant is a natural substance that is used to improve the color fastness and intensity of dyes in the dyeing process [14]. Bio-mordants are typically derived from plant sources, such as roots, bark, leaves, and fruits, and are considered environmentally friendly as they do not contain toxic chemicals [15].

Table 2. Previous research on biomordants

Title of the Previous Studies	Dye Source	Type of Mordant	Research Result
Eco-Friendly Dyeing of Cotton Fabric with Natural Dye and Mordants [16]	Banana Leaves (powder form)	Onion skins and Pomegranate skins	The use of mordants can significantly enhance both the color and color fastness
Dyeing properties of natural dyes extracted from eucalyptus [17]	Eucalyptus	Salt	Salt is used as a mordant or dye fixative in the dyeing process, which helps the dye adhere to the fabric. There are different types of salt that can be used, including non-iodized table salt, water softener salt, kosher salt, and rock salt. In addition to its fixative properties, salt also serves to adjust the pH of fabrics and even out dyes.
Effect of Temperature and Mordant on the Dyeing of Cotton Using Sodium Hydroxide Extract of <i>Whitfieldia lateritia</i> Dye [18]	Whitfieldia lateritia (powder form)	Salt (NaCl)	The study use three different mordants, namely a combination of alum and tannic acid in a 50:50 proportion, ferrous sulfate, and potassium dichromate. The post-mordanting technique is the best at keeping the color-fastness.
Biomordants and new alternatives to the sustainable natural fiber dyeings [15]	Hibiscus sabdariffa, Allium cepa and Curcuma longa.	Acacia mearnsii	The mordanting process uses a temperature of 70°C. Tannins, plants with high metal content can serves as biomordant. Examples of plants rich in tannins include pomegranate peel (<i>Punica granatum L.</i>), rosemary (<i>Rosmarinus officinalis</i>), and thuja leaves (<i>Thuja orientalis</i> or <i>Platycladus orientalis</i>). These plants offer potential as biomordants due to their high tannin content and ability to enhance natural coloring processes.
Effects of Selected Mordants on the Application of Natural Dye from Onion Skin (<i>Allium cepa</i>) [19]	Onion Skins	Iron Sulfate (FeSO ₄) Alum Aloe Vera Lemon Juice	Waste onion skin can be used as natural dye. The findings suggest that various shades of colors were achieved when dyeing the cotton fabric samples with onion skin, employing different mordants and mordanting techniques. The findings find that simultaneous mordanting with aloe vera, post mordanting with lemon juice, and pre mordanting with lemon juice have shown better results compared to the no mordanting method. The optimal recipe for producing a biomordant from aloe vera involves combining 200ml of semi-liquid aloe vera with 600ml of water, followed by straining to yield 600ml of mordant solution. Similarly, the recommended formula for biomordant preparation using lemon juice consists of mixing 60ml of lemon juice with 600ml of distilled water.
Botanical colour at your fingertips [20]	Avocado Skins and Pits	Soy Milk	The use of soy milk as mordant helps binds the protein to cellulose fibers, resulting in a darker color with increased color intensity and fastness.
Effect of turmeric dye and biomordants on knitted cotton fabric coloration: A promising alternative to metallic mordanting [21]	Turmeric	Citrus lemon and Colocasia esculenta (bulk)	To create a biomordant using citrus lemon and colocasia esculenta, the recommended ratio is 150ml of citrus lemon and 100ml of water.
Use of almond shell extracts plus biomordants as effective textile dye	Almond shell extracts	Powder of valex (acorn of <i>Quercus ithaburensis</i> ssp. <i>macrolepis</i>), pomegranate (<i>Punica granatum L.</i>) rind, rosemary (<i>Rosmarinus officinalis</i>) and thuja (<i>Thuja orientalis</i>) leaves	The dyeing process was conducted using almond shell extractions that contained biomordants at concentrations of 3, 6, 9, 12, and 20g/L. The biomordants used included valex, rosemary, Thuja occidentalis leaves, and pomegranate rind.

There are several types of bio-mordants [14, 15]:

- **Tannin-based mordants:** Tannins are compounds found in many plants that have the ability to fix dyes to fabric fibers. Tannin-based mordants include materials such as tea, and certain fruit skins and seeds like onion skins and pomegranate skins.
- **Fruit acid mordants:** Certain fruits, such as apples and lemon contain acids that can be used as mordants. These acids help to fix dyes to fabric fibers and improve color fastness.
- **Enzymatic mordants:** Enzymes are proteins that can be used to modify the structure of fibers, making them more receptive to dyes. Enzymatic mordants can be made from materials such as soybeans, and honey.
- **Alum-based mordants:** Alum is a naturally occurring mineral that can be used as a mordant. Alum-based mordants are typically used in conjunction with other natural substances, such as tannins, to improve color fastness and intensity. Aluminum acetate is a popular alum mordant for cellulose fibers and fabrics.

The properties and advantages of each bio-mordant vary, and the choice of mordant to use depends on factors such as the material being dyed, the desired color, and the availability of resources. Bio-mordants play a crucial role in natural dyeing as they enhance the brightness and longevity of the dyes, resulting in vivid and long-lasting colors.

Table 2 compiles the previous research on various types of biomordants that have been utilized and their corresponding formulas.

In addition to types of bio-mordant, there are three methods of mordanting: pre, simultaneous and post mordanting [22].

- **Pre-mordanting:** pre-mordanting is the process of treating the fabric or material to be dyed with a mordant before adding the dye. This step helps to improve the colorfastness and intensity of the final dye. Pre-mordanting is typically done by soaking the fabric in a solution of the mordant, then rinsing and drying it before adding the dye.
- **Simultaneous Mordanting:** Simultaneous mordanting is a technique in which the mordant and dye are added to the dye bath at the same time. This process saves time as compared to pre-mordanting and also helps to achieve more consistent and uniform color results.
- **Post-mordanting:** Post-mordanting is the process of treating the dyed fabric with a mordant after the dyeing process has been completed. This step can improve the color fastness and intensity of the final dye. Post-mordanting is typically done by soaking the dyed fabric in a solution of the mordant, then rinsing and drying it. This process is often used in combination with pre-mordanting or simultaneous mordanting to enhance the final color results.

In addition to the extraction of natural dyes, selecting the right mordant is highly important in natural dye process [14], because mordants can improve the intensity of the dye, producing brighter, more vivid colors, and they can also affect the color produced by a natural dye. Further [12] states that different mordants can produce different shades and hues of the same dye, increasing the range of colors that can be achieved.

The optimal ratios of biomordants can vary depending on the specific type being used. Previous research has provided valuable insights into the ideal recipes for creating biomordants, suggesting ratios ranging from 1:1 or 1:3 between the mordant extract and the water. These ratios have been found to be effective in achieving desired results in the natural dyeing process. However, it is important to note that the exact ratios may also depend on other factors such as the type of fiber, the desired color outcome, and the specific dye being used. Experimentation and adjustment of ratios may be necessary to achieve the desired effects in each individual case [17, 18, 21].

In addition, availability is an important factor to consider when choosing the right biomordant. The availability of natural resources and plants used to extract biomordants can vary depending on the location and seasons [23].

2.3 Organic fabric

Some of the organic fabric that are commonly used for natural dyeing and have been extensively researched include [13, 24, 25]:

- Cotton is a versatile and widely available natural fiber that is commonly used for natural dyeing. It is a cellulose fiber that is easy to dye and produces vibrant colors.
- Wool is a protein fiber that is obtained from sheep, goats, and other animals. It is commonly used for natural dyeing and is known for its ability to produce rich and deep colors.
- Silk is a protein fiber made from the cocoons of silkworms. It is an exquisite and high-quality fiber that is frequently dyed naturally.
- Linen is a long and strong fiber that is obtained from the stems of the flax plant. It is a strong and durable fiber that is commonly used for natural dyeing and is known for its ability to produce bright and clear colors.
- Hemp is a natural fiber derived from plants and belongs to the category of bast fibers, obtained from the stem of the plant. Similar to linen and other fibers like ramie, jute, flax, and bamboo, hemp is considered a sustainable option with lesser negative impact on the environment.

2.4 The role of color in toys for babies

Colorful toys can help babies develop their eyesight and maintain their attention [7]. Research study [8] have found that color carries critical importance in the development of children's cognitive skills. Bright and colorful playrooms can affect a child's development by shifting bad moods and providing them with vocabulary to describe the world around them. Additionally, warmer colors like orange and yellow can have a significant effect on developing children [26].

According to study [27] combinations of green and orange or green and red make some of the best neutral nursery paint colors to stimulate a baby's mind and encourage cognitive development. In addition, primary colors such as red, green, yellow, and blue are also especially appealing to young children, while black and white, pale yellow and bright purple, dark green and red, navy blue and orange, or maroon and light yellow can provide high contrast shapes to aid in visual development.

2.5 Design guideline for sustainable toys

The study focuses on designing sustainable toys for babies because they have delicate skin and their immune systems are still developing, so it is important to ensure that the toys they play with are non-toxic and free of harmful chemicals [9]. In addition, previous research has suggested several guidelines for designing sustainable toys that are safe, environmentally friendly, and provide years of enjoyment. These guidelines serve as a foundation for creating toys that align with sustainable principles. Safety and environmental protection are the core pillars of sustainability, making them essential prerequisites for any research conducted in the field of sustainability [28, 29]:

- **Children's age development:** Designers need to take into account the various stages of child development such as physical, cognitive, sensor-motor, social, and emotional development. By doing so, they can design toys that cater to the real needs of children at different stages of development instead of just following the latest trends or market demands. It is important for designers to understand the specific needs and capabilities of children at different ages to create toys that are both safe and developmentally appropriate. This approach ensures that children receive toys that are not only enjoyable but also beneficial for their growth and development.
- **Material Selection:** When deciding on the best material for toys, several factors must be considered. First, designers should consider the materials' safety; they should be nontoxic and pose no risk of injury; additionally, designers should consider the material's environmental impact. Organic cotton, bamboo, and wood are examples of sustainable materials. Second, designers should select materials that are long-lasting and difficult to break or tear. Third, designers should consider the cost of the material and choose materials that are within the target market's budget. Fourth, designers should consider materials that are locally produced and closer to production location. This can reduce carbon emissions by limiting the amount of energy needed for transportation. Fifth, designers should take into account the manufacturing capability of materials that are simple and easy to produce using standard manufacturing processes.
- **Durability:** Designers should design toys that are durable so they can be passed down from one generation to the next. To design durable toys, designers should use high-quality materials, and the toy should be well constructed and assembled. There shouldn't be loose parts that can break off easily. Prior to bringing the toy to the market, designers should test the toy to ensure that it can be played safely and can withstand normal usage.
- **Versatility:** Designers should design toys that can be used in a variety of play-education scenarios, encouraging creativity and imagination. In addition to multiple play scenarios, designers also should design toys with challenges that can be adjusted, so the toys can continuously support children's growth and development while also keeping them entertained.
- **Recyclability:** Designers should think about using recyclable materials like paper, cardboard, and recycled plastic. Aside from selecting recyclable materials, designers should also reduce design

complexity by avoiding the use of multiple materials or complex designs that may make the toy difficult to recycle. Designers should use standardized components and shapes that can be easily separated for recycling or repurposing to reduce complexity.

- **Packaging:** Designers should consider using eco-friendly and biodegradable packaging materials, such as paper or cardboard, instead of plastic, because choosing sustainable packaging may reduce the amount of waste generated by the toy. In addition, now consumers are increasingly aware of the role of packaging in the environment and are willing to act on them [30].
- **Manufacturing Process:** Designers should make sure that the manufacturing process is environmentally friendly by reducing waste, ensuring the availability of materials in the future, and minimizing the impact of transportation. This can be done through strategies such as reduction, reuse, recycling, and remanufacturing which reduce pollution and industrial waste. In addition to process, designers should also consider the level of expertise and skills required for the manufacturing process to ensure that it can be easily replicated.

3. METHOD

The present research employed a qualitative exploratory study design with experiment and design approach to investigate the topic of designing sustainable toys with natural dye, which has not been thoroughly investigated previously. The research methodology involved a multi-step process. First, a comprehensive literature review was conducted to examine previous research on natural dye, including its process, type of textile, and plant sources that can yield colorful dye. In addition, previous research on sustainable toys was also collected. Second, experiments were conducted to determine the optimal source of plant and fabric that can yield the best color and are suitable for children's development. Third, the design process was implemented to create two sustainable toys using natural dyed fabric, incorporating the sustainable toys guideline. Fourth, the prototypes were tested by fifteen moms to gain initial feedback. Finally, the study generated design methodology recommendations for creating sustainable and colorful toys that are safe for babies with the age of 0-6 months.

4. RESULT

The research's results section is primarily divided into two parts. The first section describes the experimentation process, which aimed to identify the wide range of hues that can be achieved using plant-based dyes on natural fabric. The second section outlines the design process, which involved the utilization of naturally dyed fabric as the important material for creating soft toys that are sustainable and provide sensory stimulation to babies aged 0 to 6 months.

4.1 Experimentation

The research team conducted multiple experiments aimed at extracting colorful dyes from plants. Please refer to Table 3 for the specific recipes used in each experiment.

The study employs four types of bios mordants that have proven successful in prior research: salt, vinegar, lemon juice, and soy milk. Additionally, the study utilizes five types of organic fabrics that are readily available in Indonesia and near the designer's residence. These fabrics include Hemp, Cotton (mori), Calico, Cotton (Paris), and Cotton Combed. As recommended by authors [28, 29] designers should prioritize the use of locally sourced materials that are closer to the production site.

The experiments are divided into four stages: the first stage aims to extract various color from the plants. The second stage aims to identify the optimal bio mordant that enhances color intensity and fastness on the organic fabric. The third stage focuses on identifying the most suitable organic fabric that can absorb color effectively. Lastly, the fourth stage involves conducting washing tests for five cycles to assess color fastness.

Results of the four stages of experiment are described in Figure 1 and Figure 2.

Table 3. Natural dye experimentation measurement

Measurement	Time (Low heat 90°C)
3 pieces of avocado skins with 1.5L of water	1 hour
4 mangosteen skins with 1.5L of water	1 hour
50 grams of turmeric with 1.5L of water	1 hour
250 grams of red cabbage with 1.5L of water	45 minutes
1 bunch of spinach with 1L of water	1 hour
15 grams of onion skin with 1.5L of water	45 minutes
50 suji leaves with 1L of water	45 minutes
10 grams of butterfly pea flowers with 1.5L of water	1 hour



Figure 1. The experimentation process of dyeing fabric with natural plant-based dyes

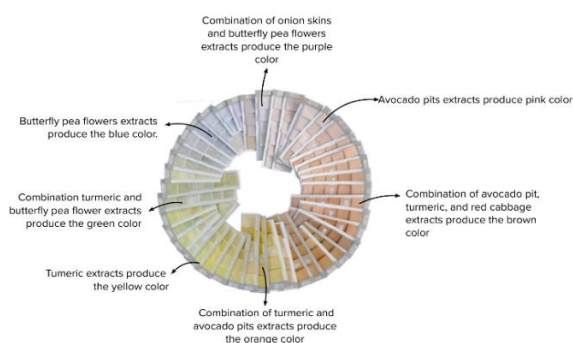


Figure 2. The wide range hues of plant-based dyes

From the four stages of experiments, we conclude that:

In order to extract color from various parts of plants, it is recommended to utilize a low heat approach, employing temperatures ranging from 60 to 90°C. This method facilitates the smooth extraction of color without exposing the sample to excessive heat.

To obtain strong colors, researchers have identified several effective plants (see Figure 2), including avocado pits (which produce pink with a color to water ratio of 1:10), turmeric (which generates yellow with a color to water ratio of 1:30), and butterfly pea flowers (which produce blue with a color to water ratio of 1:60). By combining different color extracts in a 50:50 ratio, a wider range of colors can be achieved (see Figure 2). For example, purple can be produced by combining onion skins with butterfly pea flowers, orange can be produced by combining turmeric and avocado pits, and green can be produced by combining turmeric and butterfly pea flowers. Lastly, the combination of avocado pit, turmeric, and red cabbage extracts can produce brown.

In the second stage of our experiment, our objective was to determine the most effective bio mordant for enhancing the color fastness of organic fabrics. After conducting several trials and evaluations, we concluded that the best treatment method was pre-mordanting with salt, using a water-to-salt ratio of 1:4. pre-mordanting with soy milk, using a water-to-soy milk ratio of 1:5, closely followed as the next best option (see Figure 1). The results highlight the critical role of pre-mordanting in enhancing the color fastness of organic fabrics. This finding is supported [15] who demonstrated that utilizing pre-mordanting can significantly enhance color intensity and uniformity.

During the third stage of our experiment, we discovered that both hemp and cotton fabrics were highly effective in terms of absorbing natural dyes. This is supported by the findings of study [25], who observed that these fabrics demonstrated the ability to produce vibrant and consistent colors due to their strong natural fiber structure and high moisture retention. Our findings suggest that designers and textile manufacturers should consider using these fabrics if they aim to produce high-quality, naturally dyed textiles. In addition to the effectiveness of absorbing natural dyes, hemp provides a rough texture, which can offer beneficial tactile stimulation for babies. On the other hand, cotton has a softer texture, making it gentle on the baby's skin.

In addition to hemp and cotton effectiveness in absorbing natural dyes and serve the function of soft toys. Both are sustainable materials because they require less water and land to grow than other crops such as cotton [31]. Hemp's production requires less than a third of the water needed for cotton and yields 220% more fiber. The plant grows without the need for harmful herbicides and pesticides, replenishing soil quality [32] Organic hemp is one of the most sustainable fibers with less harmful environmental impact [33]. Hemp generally constitutes a more sustainable, lower-impact crop that can be converted into fabric responsibly [34].

Another finding from the third stage of experiments, the dyeing process, researchers found that additional heating is necessary for better dye results. Colors are absorbed faster and become more concentrated when a small flame is used during the dyeing process. However, it is important to ensure that the dyeing of the fabric is even during the heating process by frequently turning it over. Additionally, the duration of soaking can also impact the level of staining concentration.

In the fourth stage of our experiment, we discovered that to

prevent the color of fabric from fading quickly, it's best to use cold water when washing. If detergent is needed, avoid exposing the fabric directly to it by first mixing the detergent with the water and then adding the fabric. When drying the fabric after washing, it should be avoided exposing it to direct sunlight. Instead, allow it to dry in a well-ventilated or shaded area. If ironing is necessary, use an iron with a cool temperature setting.

After a series of experiments to find the best material to create sustainable toys, the next step is the design process. Taking into consideration the guidelines for designing sustainable toys and the results of the experiments, we believe that soft toys are the best option. Soft toys made from organic fabrics and dyed naturally are not commonly found in the market, so there is a potential for innovation. The soft toys are designed for baby 0-6 months.

4.2 Design process

The design process is divided into three stages: ideation, prototyping and testing. On the ideation stage, researchers develop the idea to create soft toy characters from the plants that provide the color, such as avocado, onion, turmeric, and cabbage. Researchers developed two ideas. The first idea is to design soft toys based on the shapes of avocado, onion, turmeric, and cabbage. The second idea researchers developed the concept for the toys with the goal of implementing the versatility principle, which involves creating toys that can be used in multiple educational play scenarios. To achieve this, the soft toys are designed in the form of cubes with six sides that provide different sensory stimulations suitable for a baby's age and development. Each side features a unique color and texture, while a bell inside stimulates auditory senses.



Figure 4. Soft toy b design and prototyping process

During the prototyping stage, the two designs were created. To help babies develop their eyesight and maintain their attention [7], we selected complementary colors based on the experimental results. For example, blue was placed side by side with brown to achieve a color combination that creates high contrast (see Figure 3 and Figure 4). In this stage, we carefully select additional materials that are also sustainable and have less damage to the environment. Therefore, we choose organic Dacron for the soft toy inserts and pine wood. During this stage, we also ensure that both soft toys can be produced using standard sewing machines and do not require any special sewing skills for the manufacturing process, making them easily replicable.

After successfully creating two prototypes b (see Figure 5), both soft toys are tested to 15 mothers who have babies with the age of 0-6 months. During the user testing procedures, the researchers first provided an explanation of the two prototypes and highlighted their unique features, which include being made from natural materials and colored with natural dyes. Additionally, the researchers explained the educational purpose of each feature and provided different scenarios for playing with the soft toys. Then we provide the mothers with 15 minutes to interact with both prototypes. Lastly, we administer a questionnaire to evaluate their experience with each soft toy. We chose three mothers at random to receive prototypes as a thank you for their participation in the user testing.

The majority demography data of the women are as follow:

- 31.3% of women are 24-29 years old.
- 37.5% are working mothers and 31.3% are full-time housewives.
- 50% of them have a bachelor's degree.
- 80% of them come from Jakarta and Tangerang.
- 31.3% of them have babies less than 3 months old, while another 31.3% have babies aged between 3-6 months.



Figure 3. Soft toy a design and prototyping process

- The most common frequency of buying toys for their babies is once a month (31.3%), and they tend to purchase toys through online marketplaces (81.3%).

Another set of data pertains to their consumer behavior when it comes to purchasing toys for their babies.

- 68.8% of the surveyed moms are not familiar with toys made from organic and natural materials.
- When buying toys for their babies, the top three things they look for are good material and made quality, design, and an economical price.
- Their purchasing decisions are usually influenced by personal preference, expert recommendations, and discounts. As for their sustainable behaviors, they tend to reuse packaging and reduce the usage of disposable packaging when shopping.

The respondents are asked to give their response in Likert scale 1 (poor), 2 (fair), 3(good), 4 (very good) for the first soft toy prototype.



Prototype B. Box soft toys. each side has features different tactile elements that babies can touch and play with, helping to enhance their gross motor skills



Prototype A. Soft toys inspired by the natural dye-producing plants

Based on the results of exploratory studies, we have highlighted that organic fabric dyed with avocado pits, turmeric, and butterfly pea flowers can be used as a material for sustainable toys. Sustainable toys do not always have to be made from bamboo or wood. The study has demonstrated that it is possible to create sustainable toys with naturally dyed fabrics. To achieve this, we recommend using cotton or hemp as the textile, and utilizing avocado pits, turmeric, and butterfly pea flowers as sources of natural primary color. The colors can be extracted from these plants using a low-heat approach, with temperatures ranging from 60 to 90°C. It is also recommended to pre-mordant the fabric with salt or soy milk before the dyeing process. During the dyeing process, it is best to use hot water as the color absorption is better in hotter temperatures. To maintain color fastness, we recommend washing the fabric with cold water.

Table 4. User testing results

No.	Questions	Average Score for Prototype A	Average Score for Prototype B
1	Overall, this toy makes me interested	3.44	3.44
2	The color combination of this toy is stimulating enough for my baby	2.81	2.81
3	The features and functions of this toy are stimulating enough for my baby	3.25	3.19
4	This toy looks safe for my baby	3.62	3.75
5	This toy looks comfortable for my baby (made from natural materials)	3.69	3.69
6	The advantage of this toy being made from natural materials and dyes makes me interested	3.5	3.5
7	The most favorite features from the soft toys are	<ul style="list-style-type: none"> • Can be hanged • Built in bell • Educative • Soft materials • Practice gross motoric skills • It can't vibrate. 	<ul style="list-style-type: none"> • Good quality • The shape and texture on the toys • Safe material • Stimulate gross motoric skills • Different features on each side
8	The least favorite features are from the soft toys are	<ul style="list-style-type: none"> • It looks like toy for baby girls • The color is not contrast enough. • The color combination is not variative enough 	
9	I intend to buy this soft toy in the future		2.13

Aside from the experiment, we highlighted the importance of children age development, material selection, versatility, and manufacturing methods from the design guidelines for sustainable toys during the design process. First during generating ideas for the toy it is important to consider the developmental stage of children because ultimately, toys are purchased for their educational value. Second, after idea generation comes the prototyping process. During this process, it is important to select materials that are safe for babies and the environment. In addition, the materials need to be produced with easily replicable manufacturing processes. By choosing this recyclability can also be addressed. Additionally, designing toys that are versatile and made with good quality will ensure their durability and ability to be used for a long time. This finding corresponds with study [29] who also emphasizes the significance of opting for biodegradable materials for toys. This means that the current study is not the only one that advocates for the use of eco-friendly materials in toy manufacturing.

In addition to the sustainable toy design guidelines, we recommend that designers use complementary color combinations to provide colorful options for sustainable toys. The colorful options provide sensory enrichment for babies. Our research has resulted in producing pastel color palettes that can serve as a solution to a problem discovered by study [7] which showed that higher contrast colors can be a potent distractor and induce disruptive behavior in preschoolers. Another explanation is made by study [35] is that toddlers' attention is easily hijacked by distracting stimuli, and children under the age of 10 are more susceptible to interference than adults.

Another interesting finding is from the testing stage, it was found that 68.8% of the respondents were not familiar with toys made from organic and natural materials, so both prototypes were new to them. This explains why they thought that the colors were not contrasting and varied enough. Based on these results, we suggest that in the future, the market should be exposed to more naturally dyed products. They have different color palettes than synthetic dyed products. Naturally dyed products have pastel hues including pink, yellow, orange, brown, blue, green, and purple.

In regard to the favorite feature of the toys, the results show that the market understands and appreciates the high quality and safety of the materials for their babies. This finding corresponds with the research [3] which also found that most consumers associate sustainable toys with materials that are free from harmful substances. It is clear that parents prioritize the safety and well-being of their children when selecting toys, and the use of organic and natural materials can help meet these expectations. Additionally, the findings suggest that emphasizing the safety and quality of the materials in marketing efforts can help attract and retain customers who prioritize sustainability and safety.

Based on the open-ended feedback received regarding the least favorite features of the soft toys during user testing, we concluded that in the future, the educational features of the soft toys need to be enhanced by incorporating a mechanical system to meet the expectations of some mothers who desire toys that can vibrate (see Table 4). In addition to adding more features, to address the input that the toy looks like girl toy. In the future, the toy should use gender-neutral colors like yellow, green, and white instead of pink and blue.

Another interesting finding is that the respondents expressed an intention to buy the products in the future. The

combination of the functional features and the use of organic materials in the production of the toys, coupled with the fact that they are naturally dyed, has proven to be a successful strategy in encouraging the market to buy sustainable toys. This positive response can be attributed to the increasing demand for sustainable and eco-friendly products in today's market, as consumers become more aware of the impact their purchasing decisions have on the environment. Additionally, the fact that the toys are designed with the developmental needs of babies in mind and provide sensory stimulation through the use of different textures and colors, further adds to their appeal and potential for success in the market.

From the study we propose sustainable toy design methodology. The sustainable toy design methodology proposed by our research is aimed to provide designers with a valuable reference for designing successful, colorful, and sustainable toys (see Figure 6). The methodology consists of three main phases: experimentation, design, and testing. In the experimentation phase, we researched on how to produce colorful hues with different materials to determine the most sustainable and stimulating options for babies. The design phase involved using the information gathered in the experimentation phase to create prototypes that were both sustainable and functional, incorporating sensory stimulation features. Finally, in the testing phase, we conducted market research to determine the level of interest and acceptance of our sustainable toy designs. This methodology is designed to guide designers through a systematic process that prioritizes sustainability while still creating engaging and effective toys for babies. By following this methodology, designers can be confident that their products are not only environmentally conscious but also meet the needs and preferences of their target market.

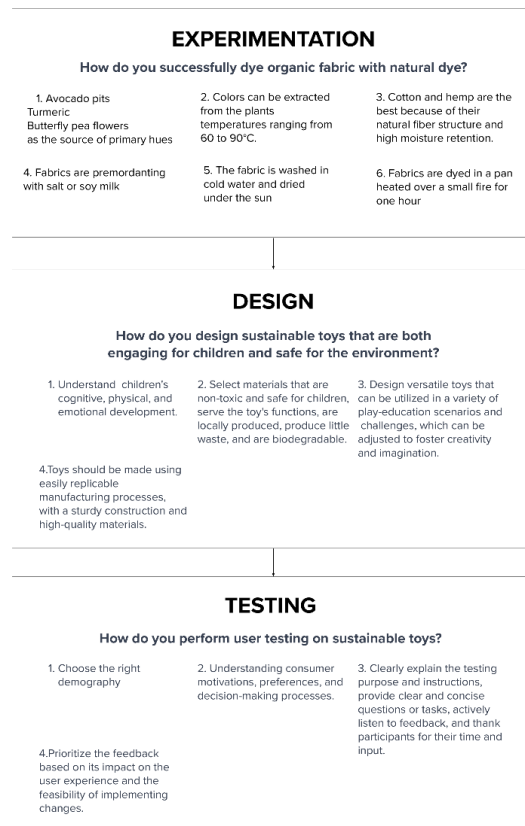


Figure 6. Sustainable toy design methodology

5. CONCLUSION

The main objective of this study was to demonstrate experimentally that sustainable toys can be made vibrant and engaging for children. To achieve this, a series of experiments were conducted to develop and test different materials, as well as to design and prototype two sustainable toys. These prototypes were then tested into the market to assess their effectiveness and appeal among target audiences. Overall, the study successfully demonstrated the feasibility of creating sustainable toys that are both colorful and attractive to children while also being environmentally friendly.

Figures 1-5 display the comprehensive view of the process for developing sustainable toys using natural dyed fabric. The methodology presented in this paper is the result of a lengthy and elaborate research on the natural dyeing process, the importance of color in toys for babies, and sustainable toy design guidelines (see Figure 6). The new methodology is tested on a design project creating two sustainable and colorful soft toys for babies aged 0-6 months.

The study makes significant theoretical contributions by linking the research on natural dyes with the research on sustainable toy design principle through the proposed design methodology. This methodology offers practical guidance for future designers who aspire to create environmentally sustainable toys, thereby making a valuable practical contribution to the field. By incorporating the principles of natural dyeing into the toy design process, designers can create toys that are not only safe and durable but also environmentally friendly.

While this study has its limitations, they can be viewed as opportunities for future research. While we focused on developing sustainable toys for babies, future research could explore the theme of sustainability education for the preschool age group. Additionally, the use of naturally dyed fabrics could be extended to other areas of children's play in school like furniture, carpets, and wall decorations. The pastel color palette proposed in this study offers a potential solution to the issue of over-stimulated and disruptive play caused by highly stimulating colors, which can negatively impact children's attention and task execution.

ACKNOWLEDGEMENT

The authors express their gratitude towards the Pelita Harapan University's Institute of Research and Community Services for facilitating this research project, which was conducted under the agreement P-054-S-SOD/I/2020. The support provided by the institute was instrumental in carrying out the study and achieving its objectives. The researchers are appreciative of the opportunity to conduct this study and hope that the findings can contribute to the development of sustainable and educational toys for children.

REFERENCES

- [1] Watson, C. (2022). 2022 global toy industry sales reach US\$36.7 billion.
- [2] Albastroiu Nastase, I., Negrutiu, C., Felea, M., Acatrinei, C., Cepoi, A., Istrate, A. (2021). Toward a circular economy in the toy industry: the business model of a romanian company. *Sustainability*, 14(1): 22. <https://doi.org/10.3390/su14010022>
- [3] AIJU. (2022). Consumer perception of sustainable toys. [Online]. Available: <https://www.aiju.es/2022/03/15/feria-internacional-del-juguete/>.
- [4] Gumulya, D., Purba, J.T., Hariandja, E.S., Pramono, R. (2022). Eco design strategies at Indonesian creative social enterprises. *Archives of Design Research*, 35(3): 7-33. <https://doi.org/10.15187/ADR.2022.08.35.3.7>
- [5] Aurisano, N., Huang, L., I Canals, L.M., Jolliet, O., Fantke, P. (2021). Chemicals of concern in plastic toys. *Environment International*, 146: 106194. <https://doi.org/10.1016/j.envint.2020.106194>
- [6] Tu, J.C., Chu, K.H., Gao, D.Z., Yang, C. (2022). Analyzing decision-making factors of green design for kid's toys based on the concept of product lifecycle. *Processes*, 10(8): 1523. <https://doi.org/10.3390/pr10081523>
- [7] Stern-Ellran, K., Zilcha-Mano, S., Sebba, R., Levit Binnun, N. (2016). Disruptive effects of colorful vs. non-colorful play area on structured play-a pilot study with preschoolers. *Frontiers in Psychology*, 7: 1661. <https://doi.org/10.3389/fpsyg.2016.01661>
- [8] Boyatzis, C.J., Varghese, R. (1994). Children's emotional associations with colors. *The Journal of Genetic Psychology*, 155(1): 77-85. <https://doi.org/10.1080/00221325.1994.9914760>
- [9] Barreto, M., Scott, M., Oakley, I., Karapanos, E., Nunes, N.J., Gomes, S., Gomes, J. (2013). Playing for the planet: Designing toys that foster sustainable values. In *Proceedings of the 31st European Conference on Cognitive Ergonomics*, 1-6. <https://doi.org/10.1145/2501907.2501947>
- [10] Geetha, B., Sumathy, V.J.H. (2013). Extraction of natural dyes from plants. *International Journal of Chemistry and Pharmaceutical Sciences*, 1(8): 502-509.
- [11] Křížová, H. (2015). Natural dyes: Their past, present, future and sustainability. *Recent Developments in Fibrous Material Science*. Prague: Kosmas Publishing, 59-71.
- [12] Uddin, M.G. (2015). Extraction of eco-friendly natural dyes from mango leaves and their application on silk fabric. *Textiles and Clothing Sustainability*, 1(1): 1-8. <https://doi.org/10.1186/s40689-015-0007-9>
- [13] Chhipa, M.K., Srivastav, S., Mehta, N. (2017). Study of dyeing of cotton fabric using peanut pod natural dyes using Al₂So₄, CuSo₄, and FeSo₄ mordanting agent. *International Journal of Environmental & Agriculture Research*, 3(2): 36-44.
- [14] Samanta, A.K. (2020). Bio-dyes, bio-mordants and bio-finishes: scientific analysis for their application on textiles. In *Chemistry and Technology of Natural and Synthetic Dyes and Pigments*, IntechOpen, 3-42. <https://doi.org/10.5772/intechopen.92601>
- [15] Pinheiro, L., Kohan, L., Duarte, L.O., Garavello, M.E.D.P.E., Baruque-Ramos, J. (2019). Biomordants and new alternatives to the sustainable natural fiber dyeings. *SN Applied Sciences*, 1(11): 1356. <https://doi.org/10.1007/s42452-019-1384-5>
- [16] Karuppuchamy, A., Annapoorani, G. (2012). Eco-friendly dyeing of cotton fabric with natural dye and mordants. *Asian Journal of Control*, 14(6): 1771-1771. <https://doi.org/10.1002/asjc.637>
- [17] Ali, S., Nisar, N., Hussain, T. (2007). Dyeing properties

- of natural dyes extracted from eucalyptus. *The Journal of The Textile Institute*, 98(6): 559-562. <https://doi.org/10.1080/00405000701556079>
- [18] Nonso, O.S., Genevieve, O., Chinedu, O., Onyinyechi, N., Kenneth, O.C. (2019). Effect of temperature and mordant on the dyeing of cotton using sodium hydroxide extract of whitfieldia lateritia dye. *International Journal of Innovative Research in Science, Engineering and Technology*, 8(6): 7301-7308. <https://doi.org/10.15680/IJIRSET.2019.0806077>
- [19] Zubairu, A., Mshelia, Y.M. (2015). Effects of selected mordants on the application of natural dye from onion skin (*Allium cepa*). *Science and Technology*, 5(2): 26-32. <https://doi.org/10.5923/j.scit.20150502.02>
- [20] Desnos, R. (2016). Botanical colour at your fingertips. Rebecca Desnos.
- [21] Hosen, M.D., Rabbi, M.F., Raihan, M.A., Al Mamun, M.A. (2021). Effect of turmeric dye and biomordants on knitted cotton fabric coloration: A promising alternative to metallic mordanting. *Cleaner Engineering and Technology*, 3: 100124. <https://doi.org/10.1016/j.clet.2021.100124>
- [22] Janani, L., Hillary, L., Phillips, K. (2014). Mordanting methods for dyeing cotton fabrics with dye from *albizia coriaria* plant species. *International Journal of Scientific and Research Publications*, 4(10): 1-6.
- [23] Vankar, P.S., Shanker, R., Mahanta, D., Tiwari, S.C. (2008). Ecofriendly sonicator dyeing of cotton with *rubia cordifolia* linn. Using biomordant. *Dyes and Pigments*, 76(1): 207-212. <https://doi.org/10.1016/j.dyepig.2006.08.023>
- [24] Mondal, M.I.H., Khan, M.M.R. (2014). Characterization and process optimization of indigo dyed cotton denim garments by enzymatic wash. *Fashion and Textiles*, 1: 1-12. <https://doi.org/10.1186/s40691-014-0019-0>
- [25] Widiawati, D. (2009). The revival of the usage of natural fibers and natural dyes in Indonesian textile. *ITB Journal Visual Art & Design*, 3(2): 115-128. <https://doi.org/10.5614/itbj.vad.2009.3.2.2>
- [26] Safferman, B.N. (2015). Impact of colour on children's play behaviour. Masters Theses, Michigan State University, USA. <https://doi.org/10.25335/M5S75H>
- [27] Ajilian Abbasi, M., Talaei, A., Talaei, A., Rezaei, A. (2014). The use of appropriate colors in the design of children's rooms: A short review. *International Journal of Pediatrics*, 2(4.1): 305-312. <https://doi.org/10.22038/ijp.2014.3204>
- [28] McLennan, J.F. (2004). *The philosophy of sustainable design: The future of architecture*. Ecotone publishing.
- [29] Coelho, D.A., Fernandes, S.A. (2013). Toy design methods: a sustainability perspective. *Advances in Industrial Design Engineering*, 167. <http://doi.org/10.5772/52858>
- [30] Carbinato, D., Batista, L., Shiran, Y. (2022). A roadmap for sustainable packaging in consumer goods. Bain & Company. <https://www.bain.com/insights/a-roadmap-for-sustainable-packaging-in-consumer-goods>, accessed on February 19, 2023.
- [31] Elliott, O. (2019). From eco benefits to legal status: everything you need to know about wearing hemp. *Fashion The Guardian*. <https://www.theguardian.com/fashion/2019/oct/02/from-eco-benefits-to-legal-status-everything-you-need-to-know-about-wearing-hemp>, accessed on February 27, 2023.
- [32] Schumacher, A.G.D., Pequito, S., Pazour, J. (2020). Industrial hemp fiber: A sustainable and economical alternative to cotton. *Journal of Cleaner Production*, 268: 122180. <https://doi.org/10.1016/j.jclepro.2020.122180>
- [33] CFDA. (2022). Hemp Materials Index CFDA. <https://cfda.com/resources/materials/detail/hemp>, accessed on February 27, 2023.
- [34] Ahmed, A.F., Islam, M.Z., Mahmud, M.S., Sarker, M.E., Islam, M.R. (2022). Hemp as a potential raw material toward a sustainable world: A review. *Heliyon*, 8(1): e08753. <https://doi.org/10.1016/j.heliyon.2022.e08753>
- [35] Goldberg, M.C., Maurer, D., Lewis, T.L. (2001). Developmental changes in attention: the effects of endogenous cueing and of distractors. *Developmental Science*, 4(2): 209-219. <https://doi.org/10.1111/1467-7687.00166>