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The implementation of polycaprolactone (PCL) as an eco-friendly material in toy design development

ABSTRACT

Due to a substantial impact of hazardous materials in toy design, numerous toy companies have opted for an eco-friendly toy by promoting a legacy of innovation rather than waste and degradation. Furthermore, one of the most significant polymers for being recognised as a safe toy material is Polycaprolactone (PCL). However, in Malaysia, the study of Malaysian parent's level of awareness in buying eco-friendly toys, their behaviour in purchasing and managing toys at home, as well as the preferences of play type for their children, is not widely discussed. Thus, forty (40) Malaysian parents have participated in an online survey conducted by the research team. The result of the study found that most Malaysian parents has a low level of awareness in buying eco-friendly toys for their children, lack the skills needed in handling broken or unused toys, and have selected criteria to be considered when purchasing a toy. Furthermore, a set of semi-working toy design was successfully developed using PCL as a proposal for potential future development and production. It is hoped that the outcome of this study will contribute to inspire future toy designers to account for Malaysian parent's preferences when developing eco-friendly toys.

KEY WORDS
Design thinking, sustainability, polycaprolactone, toy design, eco-friendly, product design

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Introduction

Nowadays, environmentalists are concerned about how plastic takes account to about 90 per cent of the toys market, especially in terms of how toys are contributing to health and environmental effects. According to Babayemi et al. (2018), worldwide plastic creation expanded from 1.5 million tons (Mt) every year in 1950 to 245 Mt in 2008, and it has been projected that it could significantly increase by 2050. Its utilization has expanded twentyfold in the past 50 years and is expected to double again in the following twenty years. Plastics present a convoluted waste management challenge at their finish of life, albeit plastic is a waste stream with recycling and recuperation potential. The challenge of plastic waste management, particularly recycling, is quick turning into a worldwide issue. Compared to the rate at which virgin plastics are produced, the rate of recycling lags far behind, and a much higher extent of plastics is being discarded in landfills, dumpsites, and ocean than at any other time. This disposition transforms the Arctic Ocean ice into a sink for micro-plastics and can last in the marine condition for many years.

In addition, during recycling the emission of volatile organic compounds may pose acute and chronic health risks in the recycling process. A wide scope of plastics contains endocrine-disrupting chemicals, for example, phthalates or brominated or chlorinated flame retardants. Such contaminants are not usually taken out in the recycling of household plastic (Hahladakis et al., 2015). According to Ismail et al. (2020), the most commonly utilized plastic material in the assembly of delicate children toys are polyvinyl chloride (PVC), which have been a significant wellspring of harmful lead especially to that of children. PVC materials that are consolidated with lead and cadmium results in improved quality, security, brightness, and adaptability. Consequently, these features have made these toys to be progressively appealing to children. Hence, a significant level of exposure to lead caused numerous adverse clinical impacts in consumers, particularly children. It can occur through oral contact when the children put the surface of toys product into their mouth, letting the lead contained inside to be moved into their biological system. Regardless of whether the item contains the low measurement of lead, this repeated exposure will put the wellbeing of the children at risk. This will, in turn, pose a danger to the cardiovascular system, kidneys, liver, immune system reproductive organs, and as well as affects the development of the brain and nervous system (Bhagwat et al., 2010; Pratinidhi et al., 2014; Tong, von Schirnding & Prapamontol, 2000). Consequently, large toy companies have opted for a greener toy design by promoting a legacy of innovation rather than waste and degradation. Besides, these companies are exploring the concept of green bioplastics (bio-based, bio composite and biodegradable raw material) as a sustainable plastic source for toys.

However, there is a lack of discussion regarding Malaysian parent’s level of awareness in buying eco-friendly toys, their behaviour in purchasing and managing toys at home, as well as the preferences of play type for their children. Thus, this is a product design research paper that aims to investigate Malaysian parents’ awareness, behaviour when purchasing and managing eco-friendly toys, and including the preferences for toy design. The investigation is hoped to generate a significant element of solutions for Malaysian parent’s level of awareness regarding eco-friendly toys. Furthermore, throughout the literature, this paper also aims to understand the significant potential of PCL as an eco-friendly material, including the possibility of incorporating the material in the product design process. Product design is a discipline that has emerged as playing a crucial part in the development of an innovative product. Incorporating a various aspect into product design through researching human behaviour, challenges, materials, and demands is one of the current methods for raising human value and product quality (Kamil & Abidin, 2013; Kamil and Abidin, 2015; Matos et al., 2014; Kamil & Abidin, 2014a; Kamil & Abidin, 2014b; Kamil, Abidin & Hassan, 2018; Sani et al., 2019; Kamil, Abidin & Hassan, 2019a; Kamil, Abidin & Hassan 2019b; Chumiran, Abidin & Kamil, 2020; Kamil, Shi & Sani, 2020; Sani et al., 2020; Kamil & Sani, 2021; Kamil, Ying & Sani, 2022; Kamil, Hua & Sani, 2022).

As a method of gathering the empirical data, 40 Malaysian parents were asked to take part in online survey. The results of the online survey revealed that most Malaysian parents are not very aware of the need of purchasing eco-friendly toys for their kids, do not really know how to handle damaged or underused toys, and have predetermined criteria to take into account when buying a toy. Following the design process, a set of semi-working toy designs made of PCL called Ebee the Interchangeable Robot was developed as a recommendation for potential future development and fabrication. The development of Ebee from PCL material is hoped to serve as a significant example for future toy designers to ensure the regulated degradability, miscibility, and biocompatibility when creating eco-friendly toys. It is also hoped that the development of toys made of PCL would assist Malaysian parents in managing broken or unneeded toys in an appropriate manner as opposed to having them go in landfills and cause major land pollution. Furthermore, the interchangeable and stacking toy body parts and other creativity and engagement concepts incorporated into the Ebee design would contribute make the toy a potential product to promote creative engagement and imaginative play.

Essential preferences in toy design

According to Gielen (2010), the design of toys and different products, including environment for playful use requires knowledge and abilities that are not all instructed in general design education. Theoretical understanding of children's play behaviour was shown to be difficult to integrate in realistic design practise on a daily basis. Strong expectations routinely overruled the knowledge; beliefs such as 'play is fun and laughter is good, so play is about laughing’. The core of play, however, can be defined as the ability to experience through self-motivated activities and behaviour at one's own discretion and will. Through the development of toys with specific functions, the needs of children can be addressed, the success of activities can be allowed, incapacity can be resolved, and frustration can be alleviated. The reliability of toys lies in how well users' explicit or implicit requirements (both children and parents) are fulfilled, both in their primary role and secondary purpose, such as affirming the sense of style and aesthetic desires of the children, or pleasant experience during use. These requirements are difficult to establish within the realm of play. However, Gielen argues that the one thing experts agree on is that play is an undertaking that is extremely open-ended.

From diverse viewpoints, which are all pleasant, fun experiences, the purpose of playing can be achieved. Play is characterised in its ability, efficiency, and content by its various degrees of opportunity. In comparison, play is coordinated for the experience itself, rather than producing a permanent effect or continuing to compensate for the effort made. Play is all about the process's enjoyability, every process. The content of play or its points is thus impossible to describe in explicit, nitty-gritty steps that a critical thinking designer might strive for.

According to Boehm & Boehm (1986), a large number of studies was conducted by psychologists and educators to decide when and how children learn. The outcome of the experiments seemed to suggest that during play, learning occurs randomly, automatically and continuously. Play is important for subsequent intellectual function, and within the play environment, different talents and abilities are developed and improved. Children use play as a way to test the limits between reality and perception. They not only use their creative minds and inventive energy by playing, but at the same time work out how to perceive themselves, their emotions, and other innate abilities. Through playing, children make an interpretation of the world to child size and reasonable proportions, where they are in control. According to Ünver (1998), specialists have been urging parents for a great period of time to search for "open-ended" toys that can be used (played) frequently in different ways. A collection of blocks can transform today into a skyscraper, tomorrow into a zoo, and the next day into a space station. The unstructured design of blocks encourages children to form as many new environments as their imaginative imagination can imagine, in comparison to a plastic castle that reliably resembles a palace.

The basic method that a child makes use of while playing with a toy is transformation. Ünver (1998) argues that the ability to make one thing that represents another is a significant accomplishment. For instance, in making the transformations of blocks to represent a cat, children tend to "play" with the desire to symbolise, which is eventually required to create a cat-like symbol; represented through the four-legged furry creature. For their symbolic activity, young children need practical toys. For instance, a toddler needs a toy phone that looks like a real phone. The pre-schooler, on the other hand, can pick up a block as a phone and carry-on conservation. There are no set rules at the heart of the action, except those generated by the player. The primary factor that convinces children about the play's imaginative reality or reinforces the belief is the toy kept in their lap. Toys are an important instrument that helps children to replicate any framework of life they can imagine (and beyond). It is then crucial that through toys, playing exercise children's' problem-solving skills to develop intellectual insights through the imaginative process, including emotional management (Oppenheim, 1987).

Eco awareness in design

According to Ceschin & Gaziulusoy (2016), the ground-breaking thesis that has brought environmental issues into the design world is 'Design for the Real World: Human Ecology and Social Change' by Victor Papanek (Papanek, 1985). Papanek gave an inside out scrutiny of the profession in design bringing up its job in empowering utilization and subsequently adding to social and ecological degradation. His work mirrored a sophisticated response centring not only to boost the outputs of the design operation but advancing change of the design profession. Ceschin & Gaziulusoy (2016) argue that the early acceptance of 'green' attitudes in the design sector did not reflect a sufficiently deep appetite for transformational change. The early examples of green design practice fundamentally centred around the idea of bringing down environmental impact through redesigning singular characteristics of individual products (Mackenzie, 1997). This was typically achieved by following the waste hierarchy in the reduction-reuse-recycle (e.g., minimising the amount of material used in the product, reusing components or entire goods in the production of new items, substituting sterile materials with recycled materials, substituting unsafe / harmful materials with non-hazardous ones). While considering the design world meant improving the productivity of product and process engineering, the prefix was the lexicon of the design profession and enhancing the still true 'rules of thumb' for enhancing the environmental performance of products. Madge (1997) stressed that green architecture lacks content and political scope, it encouraged green consumerism and did not have a substantial capacity to achieve environmental benefits.

In reminiscing to the end life of the design output which usually end up in landfills, takes into account to acknowledge the term from Cradle-to-grave to Cradle-to-Cradle (C2C). According to Hauschild, Rosenbaum & Olsen (2018), C2C draws on the concept of imitating nature in the sustainable product and system design approach. In other words, C2C explains the idea for production and consumption to allow the reduction of negative consequences in eco-efficiency and zero-emission, thus defined as beneficial to the environment. The Swiss architect Walter R. Stahel usually credits the first use of the word Cradle to Cradle in the late 1980s. Stahel argued that the "cradle to grave" perspective was merely reinforcing the existing linear economic model and relied on end-of-pipe solutions. He argued that the more sustainable solution is to use durable goods in a loop form of "cradle back to the cradle" or contemporaneously known as the circular economy. Stahel stressed that the perspective of "cradle to grave" merely validated the current linear economic paradigm and focused on end-of- pipe solutions. He proposed that using sustainable solution in a circle type of "cradle back to the cradle" or contemporarily known as circular economy is the more efficient approach.

Quality-wise, eco-design has a huge distinction over green design, although it was interchangeably used with green design when it was initially introduced. For example, eco-design places emphasis on the total life cycle of goods from raw material production to final disposal (Ceschin & Gaziulusoy, 2016). The initiative empowered profiling the environmental effect of products over all life-cycle stages, recognizing those stages with the most elevated environmental effect and in this way given key direction for design interventions. Life-cycle assessment methods helps the environmental impact assessment, empowering significant examination between various products ideas of a similar category and in this way, aides with design decision-making. On a global scale, the eco-design's aim is to minimize the utilization of energy, natural assets, and its consequent impact on the earth while augmenting benefits for customers. As proposed by Binswanger (2001) and Brezet & van Hemel (1997), through eco-design, the environment is held at the same regard as the more traditional, industrial values such as image, overall quality, aesthetics, functionality, profit, and ergonomics.

While eco-design 's life-cycle emphasis is of higher quality relative to early green design practise, it still has substantial deficiencies. As outlined by Gaziulusoy (2015), due to the lack of complexity, eco-design focuses exclusively around ecological performance and thus, ignores social elements of sustainability which involves the distribution of capital and the product's social effects of the commodity that cannot be taken into consideration in life cycle assessments. Furthermore, when so much focus is placed on the technological dimensions of eco-design, it pays little or no attention to the human-related factors (e.g., consumer actions during the process of use).

Polycaprolactone (PCL)

According to Labet & Thielemans (2009), Polycaprolactone (PCL) consists of hexanoate repeat units and is an aliphatic polyester. PCL relies on its molecular weight and its degree of crystallinity for its physical, thermal and mechanical properties. PCL is strongly soluble in chloroform, dichloromethane, carbon tetrachloride, benzene, toluene, cyclohexanone, and 2-nitropropane at room temperature; mildly soluble in acetone, 2-butanone, ethyl acetate, dimethylformamide, and acetonitrile; and insoluble in alcohols, diethyl ether, petroleum ether, and water. The uncommon property of PCL is that it is miscible with other polymers (such as poly (vinyl chloride), poly(styrene-acrylonitrile), poly (acrylonitrile butadiene styrene), poly(bisphenol-A) and other polycarbonates, nitrocellulose and cellulose butyrate) and is also mechanically compliant (polyethene, polypropylene, natural rubber, poly (vinyl acetate) and poly(ethylene-propylene) rubber).

According to Tokiwa et al. (2009), there is a high amount of biodegradation in the blends of PCL and granular starch. PCL ([-OCH2CH2CH2CH2CH2CH2CO-] n) has a medium melting point (60 °C) and a glass transition temperature (Tg) of-60 °C but high ductility as a biodegradable synthetic partially crystalline polyester. The tensile strength of the PCL is ~16 MPa and the typical modulus of its elasticity is ~440 MPa. Tokiwa et al. argue that the action of aerobic and anaerobic micro-organisms that are commonly spread in different environments has been shown to degrade PCL. Depending on the molecular weight, the degree of crystallinity of the polymer, and the degradation conditions, PCL biodegrades within many months to several years. However, Tokiwa et al. stressed that Penicillium sp. was used to perform a study on the degradation of high molecular weight PCL. Soil-isolated strain 26-1 (ATCC 36507) and the test reveals that PCL has almost completely degraded in 12 days. The polymer at higher temperatures degrades by end-chain break, and at lower temperatures it degrades by random chain break. Carboxylic acids released during hydrolysis autocatalyze PCL degradation, but enzymes may also be catalysed, resulting in faster decomposition. In the atmosphere, while PCL can be enzymatically degraded, it cannot be enzymatically degraded in the body.

Thanks to its mechanical properties, its miscibility and biodegradability with a wide variety of other polymers, PCL is one of the most essential polymers to be known as a safe toy material. PCL has been used in various areas, such as tissue engineering scaffolds (Hutmacher et al., 2001; Jenkins et al., 2006; Peña et al., 2006; Lam, Teoh & Hutmacher, 2007), in long term medication delivery devices (in particular the transmission of contraceptives), microelectronics, adhesives and packaging (Ikada & Tsuji, 2000). Its broad applicability and interesting characteristics (controlled degradability, miscibility with other polymers, biocompatibility and the capacity to be manufactured from monomers derived from renewable sources) make PCL a very useful polymer if its characteristics can be controlled and cost-effectively manufactured.

Materials, method and result

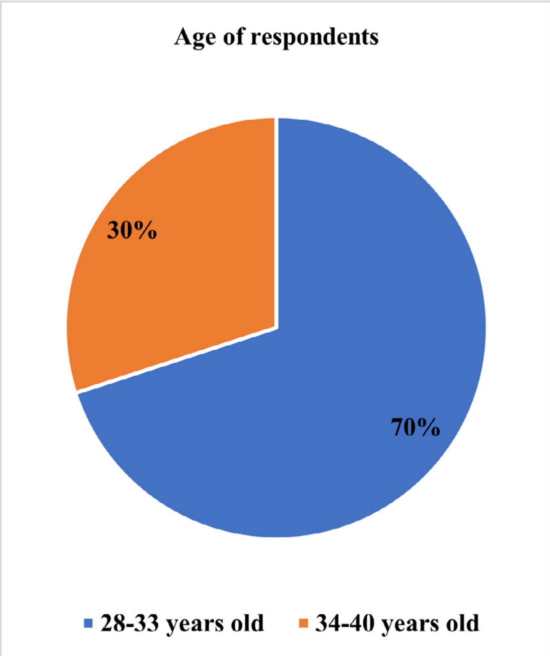
Based on findings reported from previous studies, 40 Malaysian parents were selected as respondents to participate in the online questionnaire study. Respondents were given 20 minutes to complete the online questionnaire. The context of the survey study was specifically designed as follows:

1. Malaysian parents' awareness in buying eco-friendly toys for their children such as their awareness on any eco-friendly toys in their possession, and their willingness to buy (more) eco-friendly toys
2. Malaysian parents' behaviour when purchasing and managing toys for their children such as the purchase frequency, the expenses, and what kind of initiatives taken to manage broken and unused toys.
3. Malaysian parents' preferences in toy design for their children such as the significant level

of toy's criteria preferred in toy design and the type of play preferred for the children.

Phase 1: Assessing the Malaysian parents' acceptance of eco-friendly material and the preferences for toy design

The analysis of survey study was part of the design development process to inform design needs and enforce a defined design direction. During Phase 1, the survey results was analysed to get a knowledge of Malaysian parents' acceptance of eco-friendly material and the preferences for toy design. The results of the survey study are illustrated in the following figures.

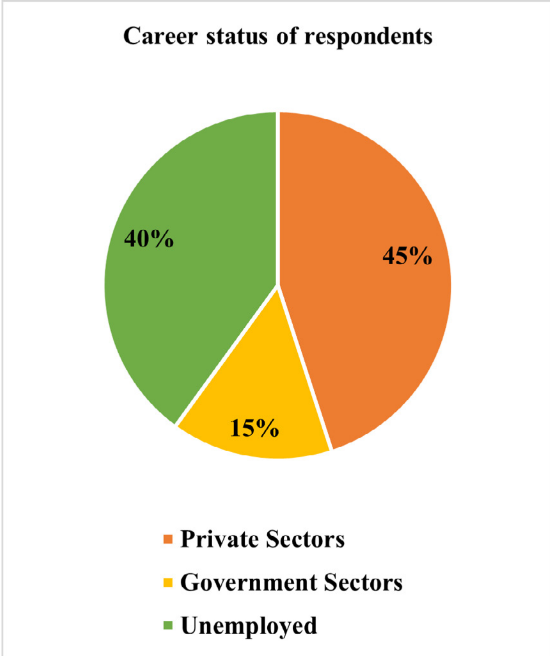


» **Figure 1:** *Age of respondents*

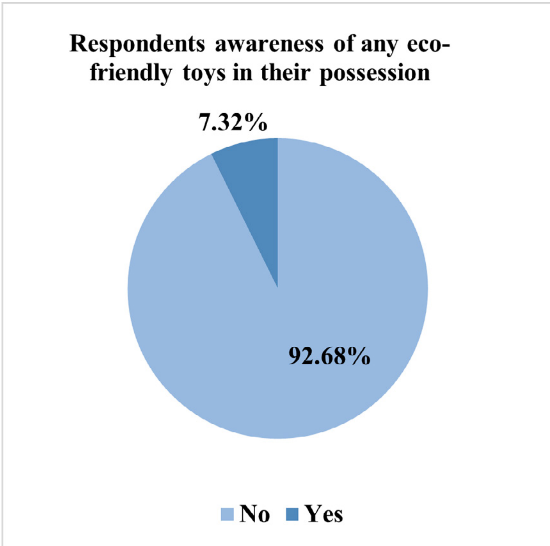
Figure 1 illustrate the age of respondents who took part in the survey. Based on the data, the majority 70% of respondents were made up from the age range of 28-33 years old, while only 30% of the respondents come from the age range of 34-40 years old.

Figure 2 illustrates the career status of respondents which indicates that the majority 45% of respondents are working in private sectors, while 15% of the respondents are working in government sectors. However, 40% of the respondents are unemployed.

Figure 3 shows the result of a survey in which respondents were asked if they were aware of any eco-friendly toys in their possession. Most Malaysian parents did not seem to be aware of any eco-friendly toys in their possession while only 7.32% of Malaysian parents did. It can therefore be inferred that the level of awareness among Malaysian parents about the purchasing of eco-friendly toys is low.

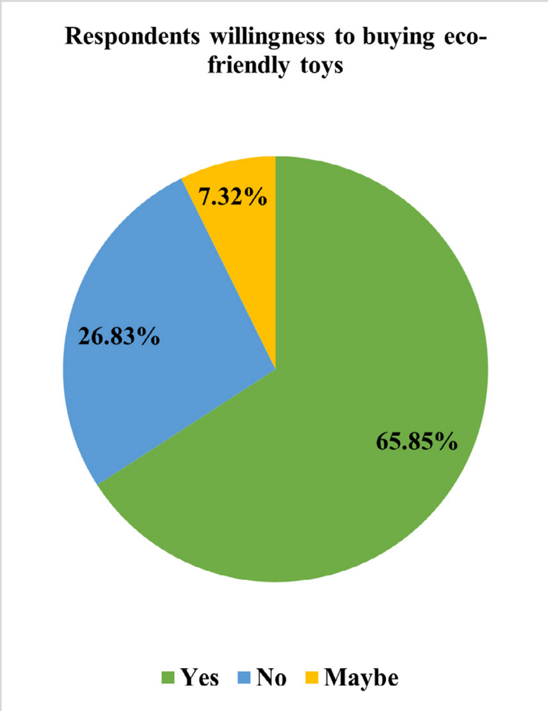


» **Figure 2:** *Career status of respondents*

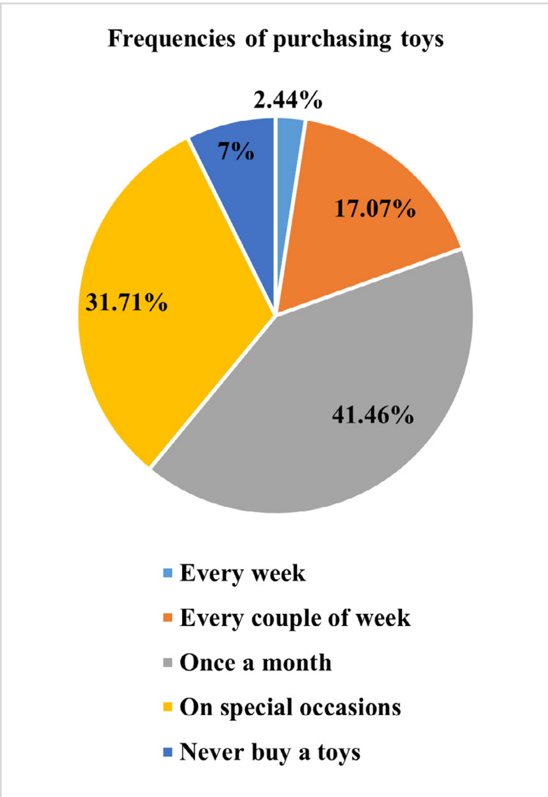


» **Figure 3:** *Respondents awareness of any eco-friendly toys in their possession*

Figure 4 shows the result of a survey in which respondents were asked about the willingness to buying eco-friendly toys for their children. Most Malaysian parents are willing to buy eco-friendly toys for their children, but 26.83% of them are not. Meanwhile, only a small minority (7.32%) are not sure of their decision. In conclusion, despite having a low awareness of any eco-friendly toys in their possession (Figure 1), there is still a glimmer of hope or potential market for eco-friendly toys in Malaysia.



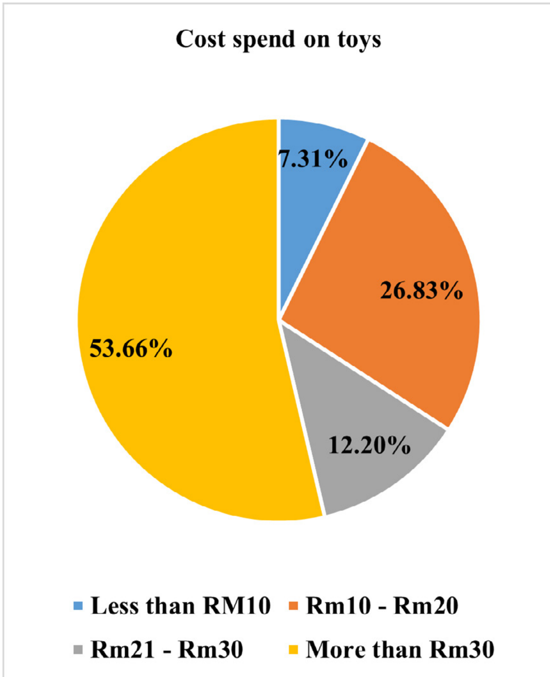
» **Figure 4:** *Respondents willingness to buying eco-friendly toys*



» **Figure 5:** *The frequencies of purchasing toys*

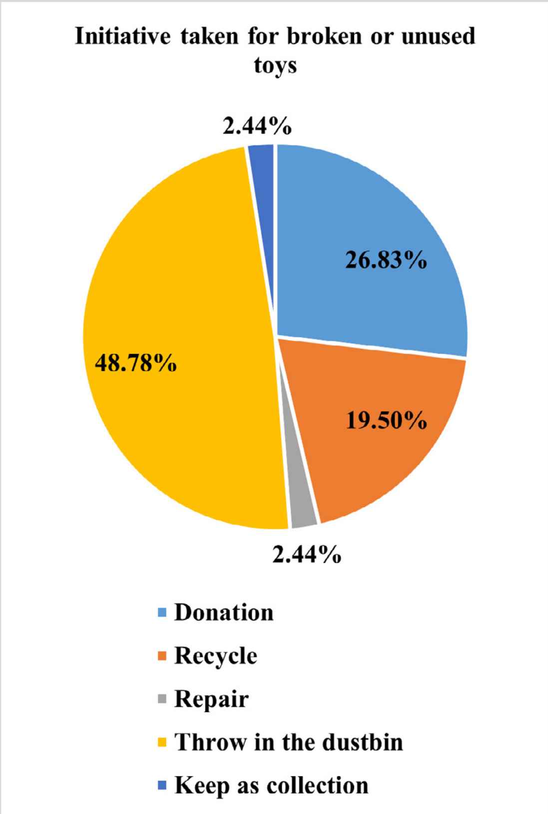
Figure 5 shows the result of a survey in which respondents were asked about their frequencies of buying toys for their children. Slightly less than half of the respondents buy toys for their child once a month (41.46%). It also shows that slightly more than a third of the respondents buy toys for their children on special occasions (31.71%), followed by respondents who buy toys for their children in every couple of weeks (17.07%), and only 2.44% of respondents buy toys for their children every week. Meanwhile, another 7% of respondents never buy toys for their children. In conclusion, despite only 7% of Malaysian parents that never buy toys for their kids, it is clear that most of the Malaysian parents did despite the varying frequencies.

Figure 6 shows the result of a survey in which respondents were asked about the cost spend on toys. The respondents mostly spend more than Ringgit Malaysia (RM) 30 (53.66%) while 26.83% of the respondents anywhere between RM10 and RM20 on toys. Meanwhile, 12.20% of the respondents spend from RM21 to RM30, and a small minority (7.31%) spend less than RM10 on toys for their children. In conclusion, it is clear that Malaysian parents are mostly willing to spend more than RM30 on toys for their children. However, the second-largest set of parents spend in between RM10 to RM30 for their children's toys.



» **Figure 6:** *Cost spend on toys*

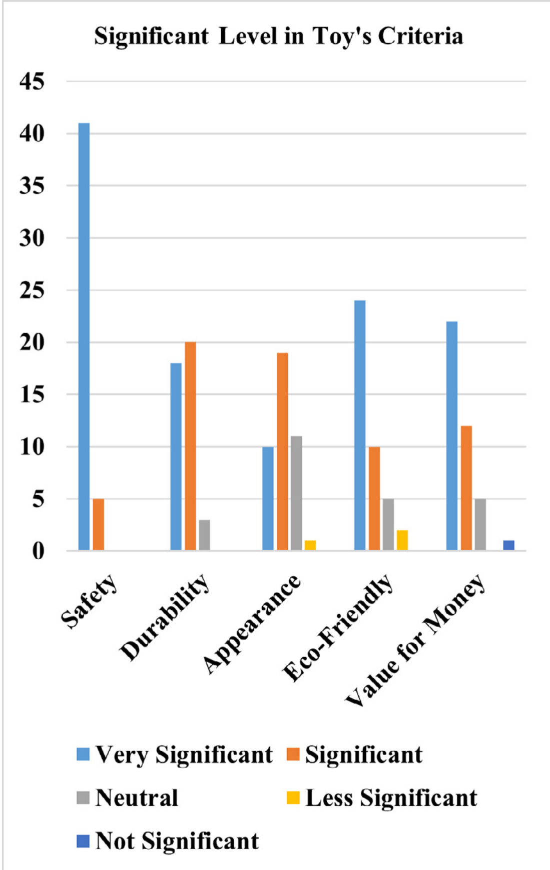
Figure 7 shows the result of a survey in which respondents were asked about the initiative taken for broken or unused toys in their possession. Most respondents throw broken or unused toys in the dustbin. However, it also shows that a sizeable portion of the respondents recycles or donate the broken or unused toys, with just 7.33% difference between the two. Only 2.44% of the respondents repair the broken or unused toys and continue to keep them as a collection. In conclusion, most of the Malaysian parents did not take any initiative for the broken or unused toys by merely throwing them straightaway. This will lead to a situation where the broken or unused toys might end up at landfill and contribute towards severe land pollution.



» **Figure 7:** *Initiative taken for broken or unused toys*

Figure 8 shows the result of a survey in which respondents were asked about the significant level of toy's criteria to purchase. Most respondents agreed that safety is very significant to be considered in toys. At the same time, the second and the third-rated criteria are eco-friendly and value for money. Meanwhile, it also shows a various significant level from very significant to not significant in multiple toy-buying criteria such as durability, and appearance. In conclusion, despite having multiple significant levels in toy-buying criteria, safety, eco-friendly elements and value for money are the criteria to be considered. However, certain elements, such as durability and appearance, should be considered too.

Figure 9 shows the result of a survey in which respondents were asked about preferred play criteria for their children. Most respondents preferred creativity, while electronic and imaginative was rated as the second and the third preferred play criteria for their children. Meanwhile, it also shows various preferred percentage on different criteria such as educational, social, and manipulative. In conclusion, despite having a various preferred percentage on different criteria, creativity elements are paramount to be considered as the main play criterion.

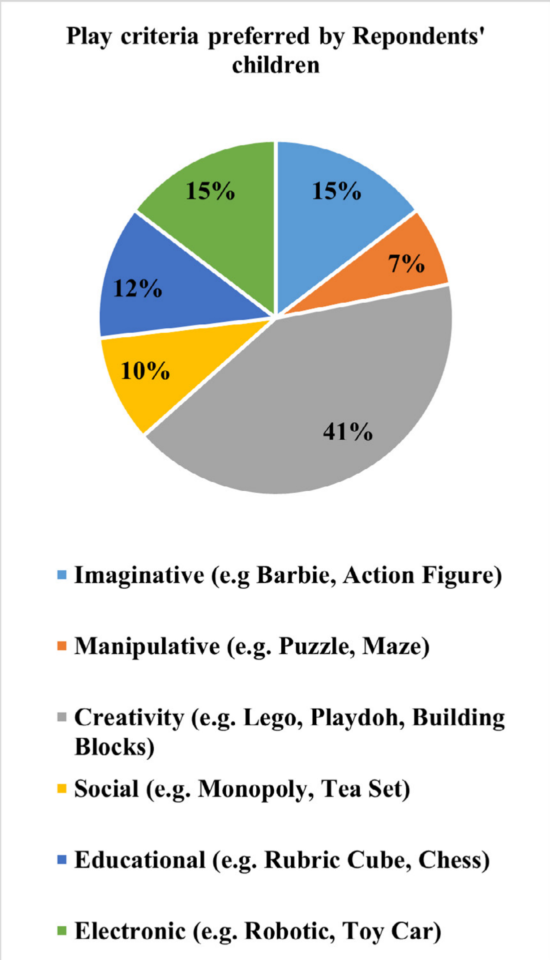


» **Figure 8:** *Significant level in toy's criteria*

Throughout the analysis of the survey, our study found that Malaysian parents did not seem to be aware of any eco-friendly toys in the possession, but they are open to the idea of buying eco-friendly toys for their children. Our study also found that Malaysian parents frequently spend on toys for their children, particularly on special occasions where the safety criteria in toys were highly considered by Malaysian parents, followed by the element of eco-friendly and the value for money. Despite having various elements in toys such as manipulative, educational, and social, creativity element in toys is highly preferred by most Malaysian parents.

These preferences are significance as a design thinking perimeter and guideline for designers to create an innovative eco-friendly toy design concept based on Malaysian parent's preferences in purchasing toys for their children. On the contrary, we also found that there is a lack of skills in handling broken or unused toys among the Malaysian parents where a broken and unused toy were simply throwed in the dustbin instead of repair, donate, recycle or keep them as a collection. This may lead to a situation where the broken or unused toys might end up at a landfill.

As global plastic dumping increased, it is now a drain in the Arctic Ocean ice for microplastics. It can remain for hundreds of years in the marine environment.



» **Figure 9:** *Play criteria preferred for respondents' children*

The understanding of Malaysian parents' acceptance of eco-friendly material and the preferences for toy design through the survey study help to determine the design knowledge that may be improved further in the toy design process. As a result, the elements of solutions were developed based on the summary of the survey study (see Table 1).

Table 1

The description elements of solutions

Elements of solutions	Descriptions
Using biodegradable material in toy design	Components of a material that is safe, regulated degradable, miscible, broadly reusable, and cost effective for a life cycle of the toys.

Phase 2: Generating design ideations

Prior to this, in Phase 1, the elements of solutions were developed as a result of survey study. Meanwhile in Phase 2, the elements of solutions aid in the brainstorming process to provide the design criteria for the toy design (see Table 2).

Table 2

The description of design criteria

Design Criteria	Descriptions
Interchangeable design	Stacking, slotting, and hooking the toy body parts to express creativity and imagination.
Emotional design	The interchangeable body parts activate the touch sensor to change the robot's 'emotion'.
Children's-inspired colour and shape	Invoke the interactive and appealing senses.
Eco-friendly material	PCL is safe, regulated degradable, miscible, broadly reusable, and cost effective for a life cycle of the toys.

Through the concept of interchangeable design, the toy design will incorporate imaginative and interactive elements. Through interactive activities like stacking, slotting, and hooking the toy body parts, it is envisioned that potential users will be able to express their creativity and imagination. A minimalist interface and touch sensor technology will also be incorporated into the toy design, giving potential users an emotional interactivity. The touch sensor is expected to be activated by the interchangeable body parts, changing and displaying the robot's 'emotions' through the installed interface. Additionally, to increase positive feelings in potential users and make the design form and interface more appealing, children's-inspired colour and shape will be employed in the design. The colour of the child-inspired design form and interface is meant to appeal to the user's visual sense and make the design look appealing and entertaining. As a safe, quality, flexible, and environmentally friendly material for design production, we have also proposed using PCL.

Phase 2 saw the initial implementation of the mood board design concept (Figure 10). Based on the design objectives, a mood board was created as a visual reference. The visual guideline utilised in this study was made using forms, shapes, colours, and interactive elements inspired by children. Based on the results of the survey study, these visual guidelines aid the research team in selecting the optimum design direction.

The design ideation process was begun with a sketching activity (Figure 11), which was based on the design concept of the mood board.

The aesthetic contour of the toy design was developed during the course of the process using elements produced from design criteria and visual guidelines in the mood board design idea.

» **Figure 10:** *Design concept mood board*

» **Figure 11:** *Design ideations development*

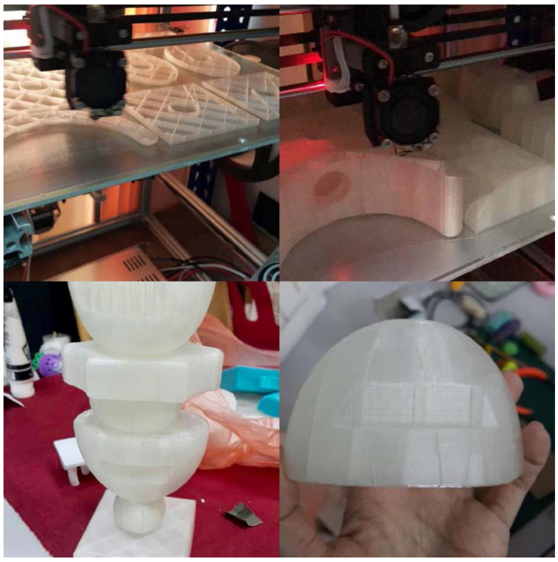
At the end of Phase 2, the output of the sketching activity was transformed into a three-dimensional (3D) design using Autodesk Inventor 3D Design software (see Figure 12). During the process, the design's dimensions and aesthetic quality were raised in a realistic manner. Gaining a complete understanding of the toy design, including textures, colours, and product dimensions, is made easier by the 3D design outcome.

Phase 3: Model making process

Model making process was carried out in Phase 3. The creation of a model aids the research team in determining the physical appearance of the product and its viability. 'Enders 3' 3D printer was used to print the model in three dimensions (based on 3D files generated in Phase 2).

» **Figure 12:** *3D design visualization*

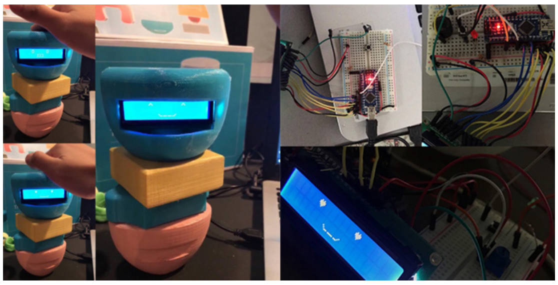
The Polycaprolactone (PCL) filament spool was loaded into the 3D printer and fed directly into the extrusion head assembly, which is where the printer's nozzle is located. The motor heats the printer's 0.4mm nozzle to the necessary temperature (around 200-210 °C), allowing it to melt, and then forces the filament through the nozzle. The chosen coordinates are followed by the extrusion nozzle, enabling the blackened material to solidify and renew on the plate. This cross-section printing cycle is carried out again, layer by layer, until the model is completely formed (see Figure 13).



» **Figure 13:** *3D printing process*

Implementing an emotional aspect in design is one of the generated design criteria, as described in the study. The 1602 blue screen LCD monitor and Arduino Nano were therefore used to programme an interactive interaction. Conduit cables, a buzzer, a 1602 blue-screen

LCD display, and an Arduino Nano (breadboard-friendly board) were all included during the model-making process. Arduino boards are extensively used in robotics, embedded systems, automation, Internet of Things (IoT), and electrical applications. These boards were originally created for non-technical customers and students, but they are now often used in industrial applications. The connectivity with other controllers and computers can be set up on Arduino boards. The board is programmed by Arduino software called IDE, equally compatible with Windows, Linux or Ios operating system. Arduino Nano is a compact, easily dismantle, and completely recyclable (Komal Kumar, Vigneswari & Rogith, 2019). In this study, the robot's (toy) expression of emotions (programmed using Arduino software) is changed by the touch sensor and displayed on the 602 blue screen LCD Display.



» **Figure 14:** *Components installation*

» **Figure 15:** *The final semi-working model*

To make sure that all design defects were fixed, continuous investigations into the technical components of the toy design were conducted throughout the process. By the time this phase was complete, a basic understanding of the constraints imposed by the toy design and how actual users would act, think, and feel while using the finished product had been attained (see Figure 14).

The final semi-working model is finished after the serial iteration phases, which involve numerous alterations to match the appropriate comfort of the user (see Figure 15 and Figure 16). The most important characteristics supporting the semi-working model include the aesthetic elements combining the current toy design style or fashion as well as the technological consideration showcasing how actual users would act, think, and feel when using the finished product.

» **Figure 16:** *Kids interaction with the semi-working model*

Discussion and conclusion

Ebee the Interchangeable Robot, built of PCL, was successfully created as an outcome of this research. Based on the study, PCL is a good option for the creation of the toy design due to its wide range of applications and intriguing properties including controlled degradability, miscibility, biocompatibility, and the ability to be made from monomers generated from renewable sources. These will let Malaysian parents to dispose of their broken or unused toys appropriately rather than having them landed in landfills and contribute to serious land pollution. Furthermore, based on the study, Malaysian parents are often prepared to spend more than RM30 on toys for their children, making PCL both commercially viable and cost-effective. Meanwhile, the study also shows that after electronic, imaginative, educational, social, and manipulative play, most Malaysian parents favoured creativity as their children's preferred form of play. This makes Ebee as a potential product to encourage creative engagement and imaginative play through the concept of interchangeable body parts. Children may express their ingenuity and imagination by borderless stacking, slotting, and hooking the toy body parts. The manipulative and collaborative element embedded in the toy design will also encourage the positive learning. The aesthetic component of Ebee through the amalgamation of children's-inspired colour and shape also envisaged to invoke the interactive and appealing senses of the children. However, this study has a limitation in that full user testing and performance evaluation of the product are needed soon to further analyse the applicability of the proposed toy design. Ebee's effectiveness as an environmentally friendly toy design has to be further investigated.

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Ebee The Interchangeable Robot, copyright number: AR2018005135 is patented under the ownership of Universiti Sains Malaysia.

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