DEVELOPMENT OF INTERACTIVE TEXTILE DEVICES AND THEIR APPLICATION

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Development of interactive textile devices and their application

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CERTIFICATE OF ORIGINALITY

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Abstract

Soft interactive textiles, such as electronic yarn, have a wide range of applications and feature in a wide variety of products. Therefore, the researcher explored electronic yarn development and interactive play mat development through two projects. The first project focused on developing electronic yarn and fabrication processes based on a project target. The researcher compared the developed electronic yarn with commercial electronic yarn, and she found that the developed electronic yarn was superior in terms of size, softness, and waterproofing. A collection of shoe uppers was also designed and developed using our electronic yarn for the fashion industry. In the second project, the researcher developed an interactive play mat, focusing on physical development in toddlers aged under 3 years. The researcher evaluated the developed interactive mats through observation experiments in kindergarten collaborative projects to connect children's movements with their exploration, play, communication, and thinking. The results demonstrate the value and practicality of the developed interactive mats. Moreover, an innovative design framework and trial experimental methods with user feedback considered the user’s experience to achieve better development in the toddlers. The study's theoretical and practical results have reference significance for the textile design industry and design education.

Publications

1. Su Yang, Su Liu, **Xujiao Ding**, Bo Zhu, Jidong Shi, Bao Yang, Shirui Liu, Wei Chen, and Xiaoming Tao, "Permeable and washable electronics based on polyamide fibrous membrane for wearable applications," Composites Science and Technology, vol. 207, p. 108729, 2021.
2. Shirui Liu, Linlin Ma, **Xujiao Ding**, Kelly C Wong, and Xiao-Ming Tao, "Antimicrobial behavior, low-stress mechanical properties, and comfort of knitted fabrics made from poly (hydroxybutyrate-co-hydroxyvalerate)/polylactide acid filaments and cotton yarns," Textile Research Journal, vol. 92, no. 1-2, pp. 284-295, 2022.
3. Rong Yin, Bao Yang, **Xujiao Ding**, Su Liu, Wei Zeng, Jun Li, Su Yang, and Xiaoming Tao, "Wireless Multistimulus-Responsive Fabric-Based Actuators for Soft Robotic, Human–Machine Interactive, and Wearable Applications," Advanced Materials Technologies, vol. 5, no. 8, p. 2000341, 2020.

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Table of contents

Abstract......i

Publications ii

Acknowledgements iii

Table of Contents iv

List of Figures...... viii

List of tables......x

List of chats......xi

Chapter 1 Introduction......1

1.1 Research Background......1

1.1.1 Need for suitable interactive textile devices for Toddlers......1

1.1.2 Definition of Interactive Textile Devices......2

1.2 Problem Statement......3

1.3 Methodology 3

1.4 Aim and Objectives 4

1.5 Significance and Values 6

1.6 Outline of thesis......6

Chapter 2 Literature Review 7

2.1 Introduction of Interactive Textiles......8

2.2 Interactive textile design and application 9

2.3 Electronic Components for interaction and fabrication method......17

2.3.1Light emitting diode (LED) 17

2.3.2 Fabrication method of interactive textile 19

2.4 Early development 22

2.4.1 The active period of brain development in toddlers 23

2.4.2 The importance of play in early childhood development 24

2.4.3 The critical physical activities during toddlers' development 26

2.4.4 Facts: interactive electronic devices used by toddlers 26

2.4.5 Competitors: Interactive devices for toddlers' development between ages 0

and 3 years 28
2.5 Introduction of Trial Experiment 28
2.5.1 Experiment and Practical Work 28
2.5.2 Questionnaire and Feedback 29
2.6 Basic safety regulations of children's products 30
2.7 Summary of research gaps 31
Chapter 3 Research of methodology 34
3.1 Introduction 34
3.2 Background of practical-based research methodology 34
3.2.1 Practice-based research methodology 35
3.2.2 Action research methodology 36
3.3 Design methodology 38
3.3.1 User-center design methodology 39
3.3.2 Rachel Studd's design framework 40
3.3.3 Baser Design Process Model 41
3.3.4 Conceptual design process 42
3.4 Color psychology in design methodology 43
3.4.1 Warm Colors and Cold Colors 44
3.4.2 The Kolenda Color Model 45
3.4.3 The Munsell System 46
3.5 Development of Theoretical Design Process Model for Interactive Textile Equipment 49
3.5.1 Needs 50
3.5.2 Problems 50
3.5.3 Conceptual design 51
3.5.4 Development of initial prototype 51
3.5.5 Evaluation 52
3.5.6 Solution 52
3.5.7 Details design 53
3.6 Summary 53

Chapter 4 Development of electronic yarn and fabrics 55
4.1 Design rationale 55
4.2 Design and fabrication of electronic yarn 55
4.2.1 Theme inspiration and color story 56
4.2.2 Target market 57
4.3 Fabrication of electronic yarn 57
4.4 Evaluation of electronic yarn 62
4.5 Design and fabrication of fabrics with electronic yarn 67
4.5.1 Handwashing test of fabric made by electronic yarn 69
4.6 Prototype shoe upper with electronic yarn 71
4.7 Reflection 73
Chapter 5 Development of Interactive Photonic Play Mat 75
5.1 Design Rational 75
5.2 Design of interactive play mats 75
5.2.1 The theme 75
5.2.2 Target market 76
5.2.3 The competitor 77
5.2.4 The color story 78
5.2.5 Fabrication method selection 79
5.2.6 Material selection 85
5.2.7 Freehand drawing for the design process 86
5.3 Scenario application diagrams 88
5.4 3D construction view of Prototype A 91
5.4.1 Explosion structure diagrams 93
5.4.2 Circuit Design Idea 93
5.4.3 Develop the process of prototype A 94
5.5 3D construction view of Prototype B 97
5.5.1 Explosion structure diagrams 98
5.5.2 Circuit Design Idea 98
5.5.3 The Development of process of prototype B 99

5.6 3D construction view of prototyping C 101
5.6.1 Explosion structure diagrams 101
5.6.2 Circuit Design Idea 102
5.6.3 The development process of Prototype C 104
5.6.4 Animation design 106
5.7 Programming and coding of Arduino IDE 107
Chapter 6 Evaluation of the interactive play mat 110
6.1 Comparison trial experiment with toddlers in kindergarten 110
6.2 Public welfare science exhibition and feedback 119
6.3 Feedback from the principal of the cooperating kindergarten 120
6.4 Concluding remarks 122
Chapter 7 Conclusions 123
7.1 Summary and Conclusions 123
7.2 Contributions 125
7.2.1 Contributions to theoretical research 125
7.2.2 Contributions to practical research 126
7.3 Limitations of this study 127
7.4 Implications for future research 128
APPENDICES 129
Appendix I The electronic components and their functions refer to chapter 5.4.2/ 5.5.2/5.6.2 129
Appendix II Programming and coding of Arduino IDE 5.7 134
Part 1 Basic knowledge of the software refer to chapter 5.7 134
Part 2 Instruction in coding refers to chapter 5.7 136
Appendix III Questionnaire Samples 6.1 140
Part 1, Questionnaire sample for kindergarten trial experiment 140
Part 2, Questionnaire sample for the principal of the kindergarten 143
References 144

List of Figures

Figure 2.1 Smart shirt

Figure 2.2 E-Static Shadows textile

Figure 2.3 Haute Tech LED-coat

Figure 2.4 Kasia Molga's "Human Sensor" project

Figure 2.5 Illumination carpet

Figure 2.6 Colour-changing moonlight cushion

Figure 2.7 LED cell carpet

Figure 2.8 Screen function diagram

Figure 2.9 QR code logo of Bedtime story blanket

Figure 2.10 Interacting play activities

Figure 2.11 Interaction play activities in nursey

Figure 2.12 Conventional LED

Figure 2.13 Visible spectrum light wave

Figure 2.14 LED in woven structures: (a) plain structure (b) twill structure (c) sateen structures; (LED in blue).

Figure 2.15 Optical fiber laid-in weft knitting patterns: (a) single jersey hopsack structure; (b,c) other weft laid-in structures; (d) warp laid-in structure. Optical fiber is marked in yellow.

Figure 2.16 Tufting technic

Figure 2.17 Effective child development strategies[1]

Figure 2.18 The development of the human brain[2]

Figure 3.1 Action research diagram

Figure 3.2. user-center design methodology

Figure 3.3 Design framework[3]

Figure 3.4 Conceptual design process for postgraduate student[4]

Figure 3.5 Meaning and association of colours

Figure 3.6 Kolenda Color Model[5]

Figure 3.7 Hue contrast[5]

Figure 3.8 Value contrast[5]

Figure 3.9 Chroma contrast[5]

Figure 3.10 Arousal vs. Evaluation

Figure 4.1 Design theme boards with colour story

Figure 4.2 A schematic of the arrangement of yarn in the circular warp knitting machine
Figure 4.3 The spinning machine of the electronic yarn
Figure 4.4 Simulate electronic yarn core with Aramid paper
Figure 4.5 Structures of the electronic yarn a and b
Figure 4.6 Stimulate yarn structure in a 3D design view
Figure 4.7 Spinning system of the electronic yarn
Figure 4.8 Stimulate electronic yarn for systematic testing
Figure 4.9 Force testing
Figure 4.10 Electronic yarns using 210D PE core yarn and concept A cover yarn
Figure 4.11 Electronic yarns using 210D PE core yarn and concept B cover yarn
Figure 4.12 Lights on testing
Figure 4.13 The tensile property of electronic yarn
Figure 4.14 The knitting construction with electronic yarn
Figure 4.15 The embedded fabrics with electronic yarn
Figure 4.16 Washing testing process
Figure 4.17 Sample 1, 2, and 3 LED light chips fully occupier
Figure 4.18 Color storyboard
Figure 4.19 Shoe upper 1(left is the illustration, right is the final product)
Figure 4.20 Shoe upper 2 (left is the illustration, right is the final product)
Figure 5.1 Recommended Commercial Playmats
Figure 5.2 Colour storyboard
Figure 5.3 Laser cut designs and samples 1, 2, 3, 4
Figure 5.4 Technical drawing of extensional panels 1, 2, 3
Figure 5.5 Construction 3D look with battery
Figure 5.6 Electronic yarn connection panels
Figure 5.7 Battery circuit design and sample look set front and back
Figure5.8 Fabricated prototype 1
Figure5.9 Fabricated prototype 2
Figure5.10 Fabricated prototype 3
Figure 5.11 The tufting guns used for the interactive play mat
Figure 5.12 The “milk cotton wool”
Figure 5.13 Freehand drawing for the design process.

Figure5.14 Play mat design board for production
Figure 5.15 Scenario of Prototype A with Voice interactive and photoelectric
Figure5.16 Scenario of Prototype B Music interaction
Figure 5.17 Scenario of Prototype C LED display interaction
Figure 5.18 The 3D view of prototype A
Figure 5.19 The explosive structure diagram of prototype A
Figure 5.20 Circuit diagram of prototype A
Figure 5.21 The development process of Prototype A
Figure 5.22 The 3D view of prototype B
Figure 5.23 The explosive structure diagram of prototype B
Figure 5.24 Circuit diagram of prototype B
Figure 5.25 The development process of prototype B
Figure 5.26 The 3D view of prototype C
Figure 5.27 The explosive structure diagram of prototype C
Figure 5.28 WS2812B LED panel
Figure 5.29 The Circuit diagram of prototype C
Figure 5.30 The circuit photo of prototype C
Figure 5.31 The development process of prototype C
Figure 5.32 Animation designs
Figure 6.1 Commercial play mats 1&2
Figure 6.2 Interactive play mats 1, 2, 3
Figure 6.3-6.10 Photos of the trial experiments in cooperation kindergarten
Figure 6.11-6.12 Photos of the interaction activities in the exhibition
Figure 6.13 Feedback form
Figure 8.1 Cover of the questionnaire
Figure 8.2 Form A of the questionnaire.
Figure 8.3 Form B of the questionnaire.
Figure 8.4 Questionnaire for principal
Figure 8.5 Questionnaire for principal
Figure 8.6 Programming and coding process of Arduino IDE

List of tables

Table 2.1 The development of early childhood

Table 4.1: Comparison experiment of bending rigidity of commercial electronic yarn and electronic yarn with FCBA

Table 4.2 Time record

Table 6.1 The data collection of toddler’s significant movements

Table 6.2 Duration time (mins)

Table6.3 Experience Satisfaction Index of Interactive Playmat

Table 6.4 Experience satisfaction index of the commercial Playmat

Table 6.5 Interesting index and satisfaction data

List of chats

Chat 6.1 The data collection of toddler’s significant movements

Chat 6.2 Table 6.2 Duration time (mins)

Chat 6.3 The experience satisfaction index during the activities

Chat 6.4 The Interesting index and satisfaction data

Chapter 1 Introduction

This chapter mainly introduces the research background and limitations of this paper, along with the methodology, objectives, significance and values, and study outline.

Research background

For thousands of years, humans have used textiles, from ancient animal fur to Renaissance-period cloth. Textiles have been transformed into environmental materials in the knowledge and technology age. An “interaction textile” environment can interact with humans through the five senses (i.e., auditory, visual, smell, touch, and taste), stimulating interaction between users and the environment. Through new product design creativity, interactive textiles may directly affect users’ sense of experience and creative interaction with the material environment. Users can also become cocreators of customized experiences corresponding to various emotions. Interactive intelligent textile applications fundamentally change people's relationships with products and how they use them. The integrated electronic functions also impact how products are designed and materials are developed [6]. Interactive design is a comprehensive discipline that relies on designers’ combined scientific and technological knowledge, experience of aesthetics judgment, and empathy for potential user groups to consider the layout of product interaction systems and platform use [7].

1.1 Research background

1.1.1 Need for suitable interactive textile devices for Toddlers

Research has shown that few beneficial electronic interactive products are suitable for toddlers aged up to 3 years [8]. The characteristics of toddlers in this age range are sensory motor exploration and precognitive development [9]. According to data in this study, out of 877 toddlers aged 3-4 years in 18 kindergartens of Hong Kong, 74.54% reported using electronic entertainment devices. In other countries, such as United States, 96.9% of toddlers reported using electronic entertainment devices before 1 year of age. In addition, 98% of toddles aged 3-4 years in the United Kingdom reported using electronic entertainment devices[10, 11]. Given today's rapid technological development, preventing toddlers from using electronic products is no longer possible. Therefore, this study focused on developing interactive products suitable for this age. The researcher aimed to encourage toddlers to shift their focus from electronic screens to a secure interactive environment integrated with textile and electronic technology, stimulating their interest and engaging in spontaneous physical interactions.

1.1.2 Definition of Interactive Textile Devices

"Interactive textile devices" is a new, transformative research field including the sense, response, and adaptation to external conditions or stimuli, manually or programmatically. The term refers to structures, functions, mechanisms, and feature technologies for sensing, communication, storage, drive, and energy acquisition using a single fiber- or text-based interactive device, as well as multi-scale computational engineering techniques, for designing and implementing smart fiber products for specific or multifunctional applications [12].

1.2 Problem Statement

Experts have suggested that prolonged viewing of electronic screens can cause poor posture and reduce exercise frequency, potentially causing health problems. Therefore, experts advise against the use of computers by toddlers under 4 years of age [13]. Moreover, few beneficial electronic interactive products are suitable for toddlers aged 0–3 years [8]. In particular, most interactive textile devices on the market still have problems, such as being bulky, inconvenient, fragile, and confusing [14]. However, research data are lacking on the use of sound or light emitted by products designed for this age group. Also, few products incorporating soft textiles and electronic functions have been developed for children aged under 3 years. Thus, the research on and production of such products represents a gap in the interactive textile market. Therefore, the researcher adopted a user-centered design and research method, prioritizing user needs, integrating technology interactive functions, sensors and lighting, music, and other applications into textiles to develop an immersive interactive play system for toddlers. The researcher collected suggestions through data from our comparison experiments for future production.

1.3 Methodology

In this study, a user-centered design process was used. An interactive product that benefits toddlers' development was the main focus. In the works, the user-centered design methodology research method was divided into four parts: a clear understanding of users, tasks and environments to identify user needs, specific requirements, and product design solutions to be evaluated and refined in a user-centric manner. Then, we solved the whole user experience problem, adjusted the product details from the user's experience with the product, and created the final interactive textile environment prototype for the user.

The literature research focused on recent interactive textile products for toddlers. The technologies and application of the interaction method were further investigated. Moreover, the fabrication methods that could be applied to develop the outer layer of the interactive textiles were studied.

The practice-based research method was also adopted in this research. In this research, based on design and practice, the method was divided into five stages: research, analysis, prototype, evaluation, and details design. This research approach is widely used in design and philosophy [15].

1.4 Aim and Objectives

This project aimed to study the development and application of interactive textile devices. The study started with electronic yarn development and then adopted related knowledge to develop an interactive textile environment with sensing, communication, and other functions via innovative design ideas for toddlers. The specific objectives were as follows:

- To apply both practical research and user-centric methodologies during the research works.

- To design and develop the soft, finest, strong strength, high flexibility, and good washability optoelectronic yarn.
- To evaluate the properties of the developed electronic yarn.
- To design and fabricate prototypes with the finalized optoelectronic yarn collection in shoe upper.
- To investigate the technology and application of recent interaction electrical components.
- To adopt a user-centered design method in the research process, prioritizing user needs, integrating technology interactive functions, sensors and lighting, music, and other applications into textiles, and developing the textile-based immersive interactive play system for toddlers.
- To finalize the detailed design specification for prototypes after the trial experiment with toddlers.

- To explore the fabrication methods for interactive textiles and related methods to create the related prototypes for all processes;
- To finalize the detailed design specification for prototypes after the trial experiment with toddlers; and collect suggestions through data from the toddler comparison trial experiments for future work.

1.5 Significance and Values

Interactive textiles and technology are research directions of the future, when humans will care less about the visuals of textile products and more about functionality.

- The method for designing the world's finest electronic yarn (<1mm diameter), its production process, positive evaluation results, and presentation as an embroidered shoe upper prototype have been investigated.
- A beneficial interactive fabric-based play mat for toddlers has been developed and innovated with integrated interactive technology.
- The evaluation has shown positive user experience results through comparative experiments in interactive play actions, satisfaction movements, and duration time between design and commercial play mats.
- Research has developed an essential practical innovation design framework, combining practical research with a user-centered design approach.
- The contribution of this research theory and practice to the innovative design process of user experience for toddlers can benefit both industrial and educational development.

1.6 Outline of thesis

The rest of this paper is structured as follows. Chapter 2 provides a review of related literature. Chapter 3 introduces the related methodology of the whole progress adopted. Chapter 4 reviews the design concept and development process of electronic yarn. Chapter 5 focuses on the development of an interactive play environment for toddlers. Chapter 6 presents an evaluation of the prototypes and discusses the comparison trial experiments with questionnaire feedback. Finally, Chapter 7 summarizes the research of this study. The appendix includes the circuit information, programming coding and questionnaire samples.

Chapter 2 Literature Review

In this paper, the following areas are reviewed and summarized to identify the design structure and considerations for the research area of interactive textiles and their applications.

2.1 Introduction of Interactive Textiles

Interactive textiles have received great attention from the traditional textile industries and researchers in related multidisciplinary research fields [12]. With the expeditious development of technology, people are no longer satisfied with textile products' protective and aesthetic functions and have instead become inclined toward the products' additional smart functions [16]. However, the field of interaction design has different definitions for interaction. Some interactive designs focus on a particular interactive function of product design that improves human life through products [17]. Moreover, the Human Interaction Interest Group pointed out that human–computer interaction is the research design, assessment, and implementation of interactive computing systems used by humans and disciplines relevant to this study [18]. Interactive design is also an experience that deals with nonmaterial processes, emphasizing user needs and preferences [19]. One of the most challenging aspects of interactive design is that the technologies that make up design materials change so quickly, leaving no time for reflection or a more thoughtful approach [20]. Thus, one of the key questions in interaction design is how can user interaction with a system, environment, or product be optimized to support and expand the user's activities? The process should focus on identifying user needs and then designing a usable, functional, and enjoyable system [20].

2.2 Interactive textile design and application

The applications of interactive textiles are represented as structures or functions of textile materials and equipment capable of sensing and responding to ambient or external stimuli [21]. Currently, most interactive products are developed by scientific and engineering researchers focusing on technical functions. However, the electronic textile products created often lack aesthetic appeal due to technical researchers' limited knowledge of textile materials and fabrics, which diminishes the aesthetic qualities of these materials. In contrast, as evidenced by the literature review in this paper, researchers with design backgrounds concentrate on integrating their understanding of the structure and function of electronic textiles with traditional textile interactive textile devices. For example, light-emitting diodes (LEDs) have been widely used in interactive textile devices, including medical, beauty care, sensing, art performance light, and communication devices [22]. Several researchers have applied LEDs to flexible, lightweight electronic clothing [23].

Smart shirt

This Smart shirt shown in Figure 2.1 is a representative functional shirt invented in 1990. It is used for military purposes to monitor the health of soldiers. It is also the combination of technology and design that initially combined textiles with conductive materials, colour-changing materials, and electronic products.

Figure 2.1 Smart shirt

The E-Static Shadows textile

This project was designed by Dr. Zane Berzina (Cooperate with partners) [24]. LED interactive weaving installation and space with a complex electronic network which is possible to read the static electricity surrounding our daily life. It is like a sonic sounder that reacts with the presence of electric charges when humans approach, displaying the shadows represented by microelectronics and miniature LED lights. This work integrates the conductive yarn into the fabric structure. The designer used the jacquard loom technic to construct the fabric piece, producing the sample quicker in larger pieces. However, after the multiple woven structures, this production process still requires experienced workers to operate the positioning skillfully, and finally, each electronic component needs to be manually soldered onto it.

Figure 2.2 E-Static Shadows textile

Haute Tech LED-coat

Wendy Legro is a Dutch designer who designed a coat that, when people walk around, the pleats detail reveals the LED light on and off by actions. The light elements in design help to steady the fashion look. Her design combines LED light and fashion elements, which achieves advanced technology looks in fashion trend[25].

Figure 2.3 Haute Tech LED-coat

Artist Kasia Molga's "Human Sensor" project

The suit changes colors and patterns depending on the wearer's breathing and the air quality around them, as shown in Figure 2.4. Designer: British artist and designer Kasia Molga applies her latest project, Human Sensor, to clothing, a high-tech garment that changes colour to reflect the level of air pollution around it. The project, led by artists and scientists, explores themes of climate change and pollution. The project uses the model to walk through the city wearing this special clothing designed by Molga. The model's breath will change color and will also change with the black carbon content[26].

Figure 2.4 Kasia Molga’s “Human Sensor” project

Magical illumination of carpet

This illumination carpet was developed by Dutch designer, Dortith Sjardijn. She used the tufting method with electroluminescence wires into the Persian rug and cracks of the light along the woven pattern[27].

Figure 2.5 illumination carpet

Colour-changing moonlight cushion

Colour-changing moonlight pad was designed by a UK online store called Find-me-a-gift. The interaction method uses the user’s touch on the interactive textile scale to light up the designed surface. The pattern and colour of the light create a relaxed atmosphere in the room[27].

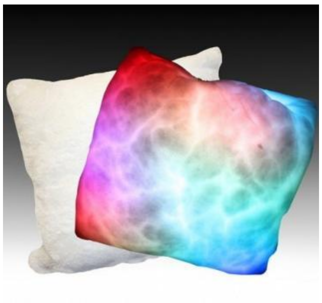


Figure 2.6 Colour-changing moonlight cushion

LED cell carpet

Yvonne Laurysen and Erik Mantel designed the LED cell carpet; they combined felt and LEDs to create a flexible carpet design. This unique design can, in the form of felt strings, be beneficial for making rugs of any size. The parts can be replaced and fixed individually if any damage happened[27].

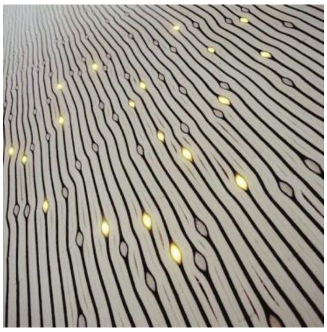


Figure 2.7 LED cell carpet

Tink book

This is an electronic interactive book as a tablet, not a textile, but the storybook creates the game mood for children, such as the Figure 2.8 below: Contextually defined story options. The toddler applies touch to one of the images, which appears with the menu, and by touching the text below as the option. Continue to press the option to appear in different weather. Those options are selected by hand and able to change sounds or images[28]. This idea could be adopted to develop textile interactive devices further. This device is suitable for toddlers ages 2-5. The function is not easy for toddlers aged 0-3 to use alone and is unsuitable for their physical development for toddlers age 0-3.

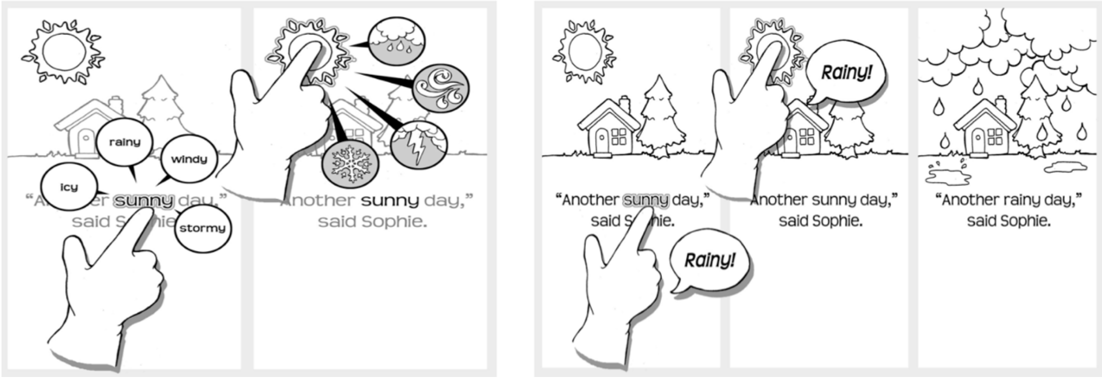


Figure 2.8 Screen function diagram

Bedtime story blanket

It is a bedtime story blanket with stories storytelling function. After scanning the QR code embroidery patterns on the bed through electronic products, the story is broadcasted through electronic products. However, this QR code is fixed, and the bed sheets do not have electronic functions. The story is still broadcasted through the functions of electronic products and software. This project is a theoretical design that expresses the connection between textile patterns and electronic products in the technological era. Moreover, this operation method is unsuitable for children under 3 years old and still requires assistance from others [29].

Figure 2.9 QR code logo of Bedtime story blanket

Interactive Soft toy book for infants and toddlers

This is a relatively new and complete interactive textile toy suitable for our target audience of toddlers 0-3 years old. This product has been tested to be safe and exciting and is a soft book that emits light and sound. Through this product project, we can refer to their integration methods, enrich interactive content, and increase interactive technology functions and aesthetics. Researchers have found that this product does not support the development of children's significant movements [9].

Figure 2.10 Interacting play activities

Fabric-based interactive surface

The fabric-based interactive surface is flexible for assisting nursey teaching to support early development in toddler classrooms. The article records a 9-week participatory recording experiment conducted by a kindergarten teacher accompanied by this product with young children, to support early cognitive, social, and emotional development in children aged 2-5. The experimental results show that the effect of this product is not very obvious, and more challenging activities are still needed to promote the development of sensation and movement[30].

Figure 2.11 Interaction play activities in nursey

2.3 Electronic Components for interaction and fabrication method

2.3.1Light emitting diode (LED)

Light-emitting diodes, also known as LEDs, are semiconductor solid-state light-emitting devices[31]. It is monochromatic light, which emits a single wavelength, and when electric current passes, it emits visible light. LED mainly comprises a PN junction chip, electrode, and optical system. It uses solid semiconductor chips as luminescent material. When positive voltages are applied at both ends, carriers in semiconductors compound and cause photons to emit light. Today's society cannot work without its participation. The sizes are small, so almost many devices integrate with LEDs inside. In addition, traffic lights, televisions, remote controls, etc., all rely on its support. Although they are tiny bulbs, they are different from incandescent lamps that they have no filament course burns out. They do not become particularly hot, so their lifespan is relatively longer. LED (light emitting diode) has a wide range of sizes, shapes, and types and can be used individually or combined into one device. The application range can be simple flicker or color change, or high power can be used for white light illumination. Special packages can make LED and optical fiber joints as high-speed data communication links. Generally, the shape of packaging on the market can be a dome, flat top or triangle, or others. Encapsulation can be transparent or colored.

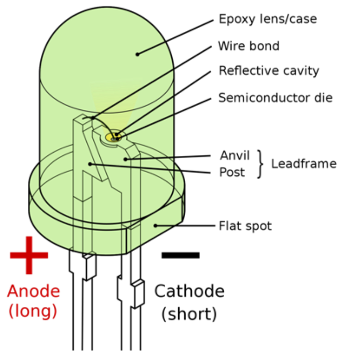


Figure 2.12 Conventional LED

Colour and wavelength

There are different types, sizes, and colors of LED. The color of LED light almost covers the solar spectrum. Currently widely used colors are ultraviolet, red, yellow, blue, green, and infrared LED. Each color releases a different wavelength, for example, blue light and purple light carry the most energy, and red light carries the least energy. The color of human visible light is 380nm~780nm in electromagnetic waves, and the color changes with wavelength in visualization shown in Figure 2.17. The infrared wavelength is more significant than 700nm; The red wavelength is 620 ~ 630nm; The orange wavelength is 600 ~ 620 nm; The Yellow wavelength is 585~600 nm; The green wavelength is 555 ~ 585 nm; The blue wavelength is 440~480nm; The purple wavelength is 350-440nm; The UV wavelength less than 350nm [32].

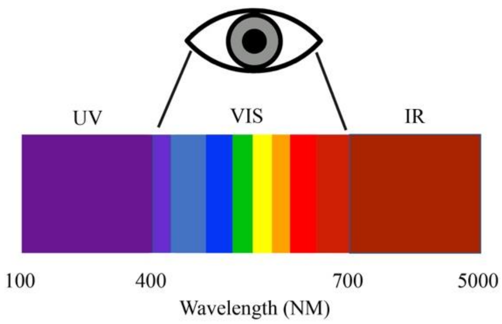


Figure 2.13 Visible spectrum light wave

2.3.2 Fabrication method of interactive textile

This research direction mainly focuses on experiments with several fabrication techniques by embedding electronic photonic yarn into the textile, improving the comfort and flexibility of wearable smart textiles. The synthesis and integration method of wearable intelligent electronic textiles is studied in this chapter and mainly focuses on weaving, knitting and embroidery. The method of integrated textile structure will be considered first through experimental prototypes in Chapter 3, and then the most suitable textile method will be determined.

Weaving method

The woven textile is made from two sets of yarn. The weave lengthwise warp yarn and widthwise weft yarn. In this operation, size and mechanical properties are the key to the combination. The electronic yarn can be integrated into any woven structure by design and consideration. The arrangement direction is mainly vertical or parallel. This method has high position accuracy and low bending loss. In this case, electronic yarns such as POF or LED wires will have some limitations in bending angle. This limitation leads to the design need to consider the reflection and transmission function in the product application requirements. The report points out that different loom patterns impact the performance of intelligent textiles through different design rules. Compared with plain, twill, and cotton satin, cotton satin can better reflect the side-emitting characteristics of optical fiber. If the wearable electronic yarn is based on commercial optical fiber, its diameter range can be 250 μ m to 3000 μ m, which will affect the strength and resistance of the fabric[33]. Figure 2.14 is the design of the woven structure as if transferring this thinking by replacing the LED electronic yarn with the same structure. These structures are based on the experimental results of related optic fiber textile woven literature, and the literature using LED electronic yarn is relatively less, so various similar structures and layer configurations can be worth using LED electronic yarn to try experiments processes and samples. If it is applied to the use against of human skin, the relevant electronic yarn can be embedded into the fabric layer.

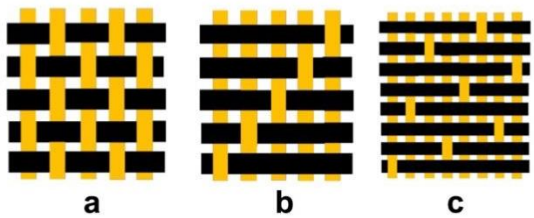


Figure 2.14 LED in woven structures: (a) plain structure (b) twill structure (c) sateen structures; (LED in blue).

Knitting method

Knitting is also a method widely used to integrate smart textiles. Weft knitting is usually used in optical fiber smart textiles to achieve an advantage in reflecting the elongation. The knitting direction is horizontal from left to right. The knitting structure will lead to more optical fiber bending in textile structures. Therefore, if the design is applied to the human body, it is necessary to test the bending, fracture tensile rate and toughness in the process of experiment and sample. It is assumed that if the softer LED electronic yarn is used to weave into the knitted structure, various optical fiber inlaying methods that have been pointed out in the relevant literature can be tried, for example, in addition to Jersey hopsack structure and the inlaying direction can also be changed to warp yarn[33]. Relevant experiments will try and measure the mechanical properties in Chapter 3.

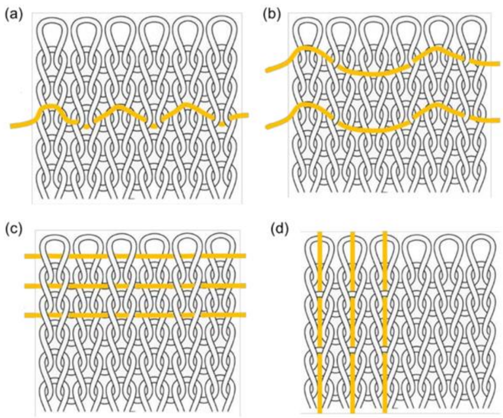


Figure 2.15 Fiber optics laid in weft pattern: (a) single-layer knitted hopsack structure; (b) (c) Other filling structures; (d) warp and weft structures. Fiber marked yellow.

Embordering method

Embroidery technology has evolved from manual to machine embroidery, widely used in monitoring, therapy, and other electronic textiles[33]. The advantage of this technology is that electronic equipment can be fixed on various textile surfaces. The limitation is that electronic devices are usually exposed to the surface. The imaginary design pattern uses LED electronic yarn to embroider on the surface of various textiles.

Tufting method

Tufting is a textile technique that continuously inserts yarn into a fabric base, creating loops or cutting tassels without knots. This requires a tufting gun to operate it in and out to make knots on the fabric canvas. This technic is flexible with the shape and pattern, usually applied to large sizes of carpet making [34]

Figure 2.16 Tufting technic

2.4 Early development

2.4.1 The active period of brain development in toddlers

Research has shown that the most critical period of brain development in a child's life is before 6 years of age. Heckman proposed that earlier intervention education for children is more effective for their future physical and mental development [1].

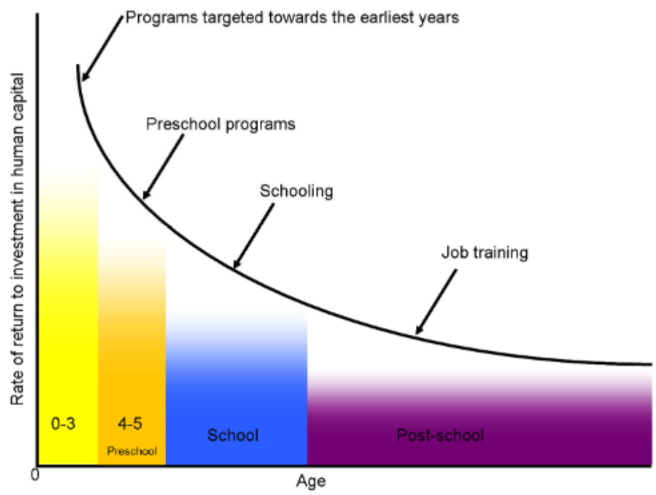


Figure 2.17 Effective child development strategies[1]

Moreover, research on children's ecological development has highlighted the importance of children’s environment, caretakers, and activities and play content in the first 3 years of life, which can impact their physical and mental growth [35]. Professor of Brain Science Psychology emphasized the importance of early childhood education and pointed out that cultivating the habit of autonomy learning in toddlers before the age of 3 years lays the foundation for their future character. In neurology, the definition of intelligence depends on the density of neural connections, determined by genes. The density of another type of neural connection is determined by acquired experience. Although children cannot change their genes, parents can intervene in early childhood development, and games are the best way to promote children's brain development Xiao Dan Xiao Dan[36, 37]. In addition, children's language development research has proved through case studies that the critical period of children's phonetic learning occurs in the first year of life. Moreover, the growth of syntactic acquisition in children's mother tongue learning is 18–36 months of age. Children can quickly acquire various syntactic elements. However, the window of opportunity for vocabulary development in children's brains is 18 months of age [2]. Figure 2.18 illustrates human brain growth activity in development in different age groups [2].

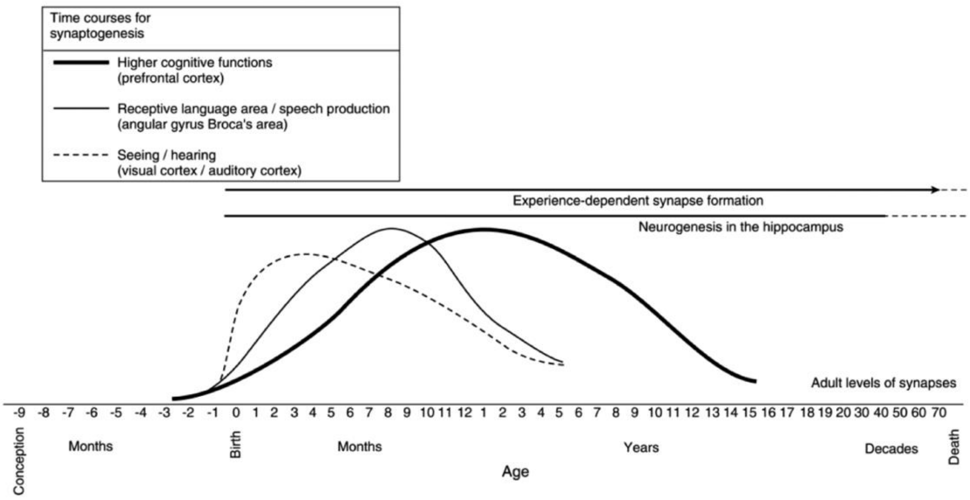


Figure 2.18 The development of the human brain[2]

2.4.2 The importance of play in early childhood development

The age range of 0–3 years, called early age development, is the most important, rapid period for children's brain development [1, 38]. Moreover, different stages of toddlers' development exist[39]. Table 2.1 summarizes preschool children's developmental and play practice needs in each stage.

Toddles development stages:

Type	Stage	Features	Proposal
Oral hypersensitivity period	4-8 M	Taste hand and anything might be interesting	Keep hands clean, gummy teeth, comfort pads, and spend more time with them
Hand sensitivity period	4-12M	Grasping, pinching, and throwing, a significant impact on intellectual development	Exercise fine movements and provide gripping and pinching of objects of different sizes and materials
Sensitive period of large muscle development	1-3YR	Likes to walk and jump over obstacles constantly, and enjoys a messy environment	Encourage children to exert their instincts and engage in emotional exercise when safe
Sensitivity period for subtle things	1-2YR	Interested in tiny things	A period of cultivating focus
Space sensitive period	1-3YR	Throw things, buckle sockets, flip boxes and cabinets	Ensure safety without obstruction, play with building blocks, climb high and drill holes
Language sensitivity period	1-3YR	Likes listening and imitating	Speak more, tell stories, read picture books, and guide the baby to speak without interruption
Imitation sensitivity period	1-3YR	The critical period of self-awareness formation, imitating others' every move	Set a good example and encourage in a timely manner
Music sensitivity period	1-5YR	Dance and sing along with the music	Perception of instrument sound, selective selection of high-quality music
Color sensitivity period	3-4YR	Likes various colors	Colorful paintbrush, free to paint

Table 2.1 The development of early childhood

Research has suggested that the best early development process for young children is play [33-35]. The task of young children at this particular age is to encounter problems and learn to solve them through different games during play. Moreover, different types of play exist. Table 2.2 shows the main types of play games used for data collection[39-42]. By collecting this data, researchers can identify the characteristics of children’s games and children’s development direction.

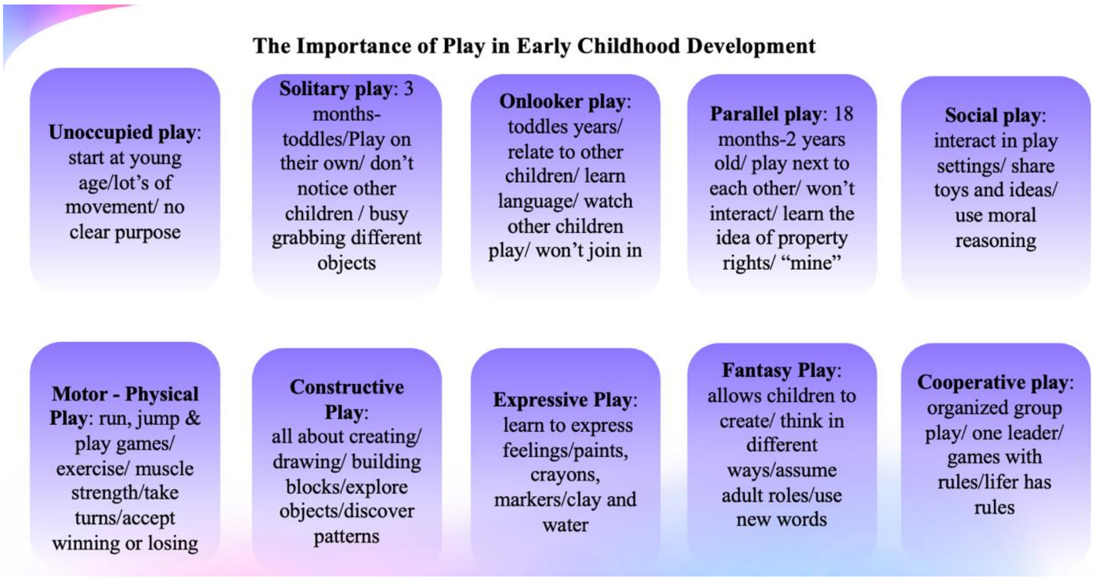


Table 2.2 The important play of early childhood

2.4.3 The critical physical activities during toddlers' development

Early childhood development usually refers to cognitive, sensory, and motor development between 0-3 years of age. Play is regarded as an indispensable part of early development. Playing games stimulates the brain by forming connections between nerve cells, which contributes to developing fine and coarse motor skills. Fine motor skills refer to activities done with the fingers, such as picking and gripping. Coarse motor skills include walking, jumping, running, climbing, grasping, and other performing movements. Play also help children develop language and social skills and teaches them to communicate emotions, think creatively, and solve problems.

2.4.4 Facts: interactive electronic devices used by toddlers

Although we know the importance of play for young children, owing to the busy lifestyle of most parents today, parents do not have the opportunity to carefully select interactive electronic products suitable for toddlers. Further, few suitable interactive devices are available for toddlers aged under 3 years. Research has indicated that most young children are exposed to electronic products too early, including smartphones, tablets, and computers. Of a random sample of 877 Chinese Hong Kong children aged 3–5 years from 18 kindergartens, 74.54% reported using such devices. In the US, almost all (96.9%) toddlers reported using digital devices before 1 year of age. Yet, 98% of toddlers in the UK reported using digital devices digital devices before 3–4 years[10]. Therefore, the researchers created a questionnaire online about why toddlers aged 1–3 years use digital devices. The most common answers are shown below.

- Parents want to try to keep toddlers busy and quiet;
- Parents can concentrate on work while children use digital devices;
- Parents believe that using education apps is helpful;
- Parents are confident in knowing how much screen time is appropriate;
- Parents react positively to toddlers using digital devices;
- Parents use tablets or smartphones to entertain children.

Is there any harm to toddlers' use of digital devices?

- Experts do not recommend that children aged under 3 years use computers, tablets, or smartphones, except for video calls [9, 10];
- A poor posture and lack of frequent exercise affect physical development [9];

- Information is inculcated in the child's brain passively, but the brain should be engaged in an active process of self-discovery, thinking, and learning [9];
- Researchers reported from a long-term trial project that the greater the use of electronic products from infancy to 12 months of age, the poorer the development of executive function by 9 years of age [10].

2.4.5 Competitors: Interactive devices for toddlers' development between ages 0 and 3 years

While some interactive children's toys are on the market, few products with soft fabrics and functional labels are suitable for toddlers aged 0–3 years. As mentioned in Chapter 2.2, a few suitable toys are Tink Book, Bedtime Story Blanket, and The Interactive Soft Book. These products have relatively simple interactive functions, but most interactive methods focus on developing cognitive abilities and fine finger movements for those aged over 3 years. Soft fabric interactive toy products do not focus on developing cognitive and physical movements [9].

2.5 Introduction of Trial Experiment

2.5.1 Experiment and Practical Work

Case study 1: The long-term observation experiment comprised a 9-week exploratory research experiment using “BendableSound,” an interactive music touch fabric product, as a qualitative test of daily activities in an early education classroom. This test included

22 young children and five teachers by observing and recording the impact of products on supporting early childhood development [30].

Case study 2: The researcher performed a comparative experiment using the virtual electronic desktop games and physical paper desktop games mentioned in the relevant literature. The participants were the same young children who participated in the case study 1, and they were observed before and after playing. By answering questions, they could determine which game was more popular and achieve the designer's goals [43].

2.5.2 Questionnaire and Feedback

The research trial experiments for the second product, “interactive play mat for toddlers,” adopted the method of case study 2. The experiment compared the developed interactive play mats and commercial play mats available. All of the participants provided their informed consent before experimental participation.

The same rule existed for both the developed interactive and commercial play mats. There were two children in a group, one male and one female, and a total of three groups. The duration of play was 30 min per group (could be added or subtracted appropriately). Four adult hosts were present, and an adult accompanied each child to observe and play one on one, taking photos and recording while ensuring the safety of the children. During this period, one primary host maintained order, while another monitored the technical aspects of video recording and the regular operation of related electrical appliances. The video recorder could be positioned around the room in advance. None of the children had seen the interactive environment to be tested or contributed to developing these technologies. This game test mainly observed the reaction (face and body actions) and playing time of the children during spontaneous play on interactive sports carpets. All of the data were collected by questionnaire and used for evaluation. The related questionnaire form used for the trial in Chapter 6 is given in Appendix I Questionnaire Samples 6.1.

2.6 Basic safety regulations of children's products

Safety standards apply to children's toys and products. Thus, the researcher first checked the updated safety standards for toys and children's products of the Economic Affairs Committee of the Legislative Council of Hong Kong[44]. Relevant content mentioned that the Hong Kong market is not large. To avoid unnecessarily increasing business costs and promote trade, specific legislation has not been passed on the safety standards of children's toys and products in Hong Kong. Instead, Hong Kong has adopted internationally accepted safety standards, including:

(a) The International Toy Self-Regulatory Safety Standards (IVTSS);

(b) European Standard 71 (EN71);

(c) ASTM standard F963.

Overall, the researcher learned the necessity of safe standard use of children's products, especially for those aged up to 3 years. For this soft interactive play mat set, it was necessary first to consider whether the surface materials that toddlers use are nontoxic and whether the practical circuit current meets safety standards. The researcher ensured that the wool used for making the carpet is children's nontoxic wool that meets standards and was purchased by relevant qualified manufacturers. Considering the age range of 0–3 years and the developmental stage of young children as the user group, the researcher also ensured that the product does not have the risk of swallowing small components or obvious structural difficulties, such as collision risk. The researcher also avoided all circuit power supply currents exceeding 24 V during design and production. Therefore, in this project, the researchers confirmed that based on the requirements of the above reference, the children's play mat set designed and developed in this project is safe and can be used for future play experiments with toddlers. Furthermore, considering the commercial external production situation, we will change the Velcro on the side opening of the carpet contacting the circuit to a fixed part requiring specific tools to open. The instructions and guide for using the product will indicate whether children aged 0–3 years must be accompanied and monitored by adults while playing. Finally, the researcher will conduct product safety testing through relevant testing institutions before commercial production.

2.7 Summary of research gaps

With the expeditious development of technology, interactive textiles have made life much more convenient. First, the literature review summarizes the research on interactive textile designs and their applications. Second, the target user group is presented (toddlers aged 0–3 years). Third, competing products for the target user group are identified. Fourth, we present research on recommended trial methods during the research process to evaluate the product. Last, the researcher presents the information on basic regulations for child product development. The literature review also discusses electronic components for interaction and fabrication methods of interactive textiles. Currently, interactive textiles with embedded electronic components such as LEDs, sensors, batteries still lack the necessary characteristics, such as flexibility, practicability, convenience, functionality, biocompatibility, and aesthetics. The researcher explored the potential of interactive electronic components uses in interactive textiles for the target user group through a wearable textile and children's interactive toy. In some cases, the textile structure was not fully applied for integration with electronic elements in the textile structure. Therefore, the gaps identified for research through this project were as follows:

- Few researchers have designed interactive textile products with both artistic and functional uses. With the expeditious development of society and technology, two requirements have emerged for functional textiles or clothing: practicality and aesthetics. A lack of the combination of the two aspects in the final design warrants closer consideration;
- Textile design frameworks are limited and do not clearly cover all the activities that take place during textile design. Despite overlaps and similarities in all areas of the design industry, a clear and rational explanation is lacking for what happens at every stage of textile design. The innovation of this design and research methodology is the design and development of an interactive textile product for toddlers that

involves toddlers in the trial stage to achieve the best final product for the target user group, as well as recording of the whole design process;

- Electronic yarn in the market at the moment is usually poor in terms of tensile strength, resistance fatigue, thermal performance, and low washing ability. Thus, a comfortable, functional textile product that uses softer electronic yarn is worth researching and developing;
- Few interactive toys are available for toddlers aged 0–3 years to learn through play. Most interactive toys available in the market are designed for children aged at least 3 years. According to the literature review in Section 2.4, play is critical in early development, an important stage for toddlers to learn through play. Therefore, it is necessary to research and develop an appropriate toy with suitable interactive functions for toddlers;
- Evaluation with a questionnaire and feedback method in a trial experiment reflected the necessary adjustments for the finalization of the development process.

This study presented deep knowledge in design and comprehensive professional knowledge by both an electronic yarn project and an interactive play mat development project can contribute to the abovementioned gap in knowledge. Therefore, in this research project, the researcher carried out relevant research for the design and production of an interactive textile product. The following chapter will introduce the methodology of the research.

Chapter 3 Research of methodology

This chapter describes the research methods for developing electronic yarn and interactive textile devices.

3.1 Introduction

Practical research methods are used in the process of electronic yarn development. In this research direction based on design and practice, the method is divided into five stages: research stage, analysis stage, design of initial prototype, evaluation stage, and details design finalized. This practical research method is widely used in design and philosophy[15].

On the other hand, the user-center design methodology was adopted in developing interactive textile devices. User-centric design methodology research method was divided into four parts, clearly understand user, task and environment, determine user needs; specific requirements; product design solution; user-centered evaluation drive and refinement, and solve the whole user experience problem. Finally, the prototype of interactive textile devices adjusted the product details from the user's use experience and created the final interactive textile environment prototype for the user.

3.2 Background of practical-based research methodology

There was almost no theoretical support for practical research in art and design until the 1974 National Council for Academic Awards changed its regulations to allow graduate students to showcase their works and written papers in art and design. The earliest Polytechnic University was established in London, England in 1880. In 1968, the concept of a practice-based methodology to research was used in the massive expansion of such institutions, with the goal of adding a service line to mainstream higher education. The professor at this school emphasized the critical value of practice. A written paper can have other forms of materials as supplements in addition to writing. Students can submit artifacts and their records together in their doctoral thesis. This means that knowledge can be improved in specific disciplines through practical perspectives. Research topics can also be developed through practice. The review will be based on the practical results and the process of thinking and arguments[45]. In addition, Schon proposed relevant evaluation processes and requirements, including insights into practical innovation and the value of early performance for other practitioners; Clear evidence of professional development and innovation can be found in practical documentation and requires a detailed description of a high level of professional creativity, sensitivity and responsibility; and a clear articulation of the relationship between research roles and practitioners[46].

3.2.1 Practice-based research methodology

Research around the nature of practice is called "practice-based research". Which is undertaken by artists, designers, curators, writers, musicians, teachers, and other practitioners. Research-based learning is not necessarily a doctoral research project, it has generated new concepts and methods for generating original knowledge[45]. Quality requirements for practice-based documents: (a) Integrating innovative insights into practice;(b) Contribute to the performance of other practitioners; (c) It provides a clear basis for professional development and innovation and details the high professional creativity, sensitivity and sense of responsibility in practical documents. and (d) Clarifying the link between research roles and practitioners' roles[46]. Mainly focusing on the new knowledge generated by the practice itself. Fully describe the research process textually, focusing on promoting knowledge practice.

This research study's stage is through a literature review, including design inspiration. The analysis stage by applying into consideration the user needs in the market. The design of the initial prototype stage is the process of the preliminary experiments and proofing of the designed products. Details design finalized by observation is usually aimed at the results and evaluation of product experiments. Reflection is to further modify the prototype through the experimental results of the product. The planning phase reviews and considers design and research errors. Therefore, design consideration achieves the research gaps. In the final stage, the technical difficulties in the experiment will be classified and solved. The product design can adjust and break through the technical difficulties through the experimental results. Design through the reflection stage to modify the analysis of the prototypes that achieve the final improvement.

3.2.2 Action research methodology

Many unknown problems have been found by using action research methodology in the recent stage of research direction. The experiment is one of the most direct methods to solve the related problem. This research method provides a cycle of assessment, repeated until the problem is solved and the goal is achieved.

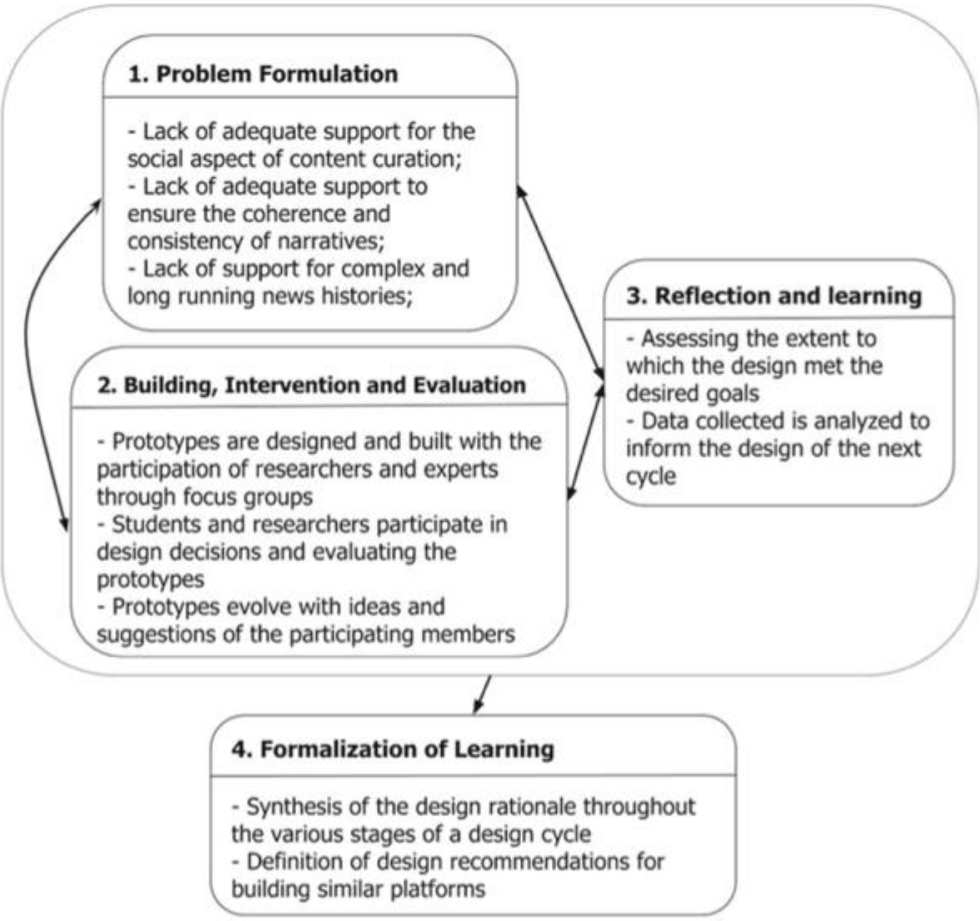


Figure 3.1 Action research diagram

In the field of design, literature research often refers to the combination of design and action research methodology in Figure 3.1, For example, it will start with defining problems and solving problems, then inventing and evaluating, then reflecting on learning, and finally systematically presenting the results and summarizing them in formula [15]. This method is a cyclical behavior that designers are familiar with, including the periodic behaviors that will be reviewed, modified, adjusted, and reflected before the initial design concept is formed[47]. In the initial product development process, using this behavior of action research methodology leads to product problems and solves the related difficulties directly. The relevant literature points out that action research can enhance the practitioners' experience of self-consciousness knowledge in a fixed period, obtain valuable knowledge output, promote the next research stage, and finally achieve the research objectives[48]. Moreover, action researchers diagnose and solve problems in action research. The primary method is cooperating with customers or organization members to develop this solution [4]. For example, the social world is constantly changing, and action research will explain that researchers and research are also changing [5]. It can also be said that action research includes positivism, hermeneutics, and criticism. Positivist action and classical action research have the same meaning. This research method is interpreted as a social experiment and a method of monitoring hypotheses in actual society. Hermeneutics action has the same meaning as contemporary action research, which regards business reality as a social construction and simultaneously pays attention to local and organizational factors. The criticism action is a unique research method, using targeted research action to improve the business process. The above three kinds of action research need to consider the following characteristics of action research: this kind of application is to improve the specific practice, conduct action, evaluation, and Analysis based on collecting relevant data, and finally, better improve the practice. This research method is mainly multi-faceted cooperation to achieve a common goal.

3.3 Design methodology

The design methodology is a necessary step in this project. This chapter will gain an understanding of the appropriate design framework through the design process in various design fields. Designers use their knowledge to find the best solutions in design. However, the choice to use this selected idea can be made by each design specification, depending on the license level, standards, processes, and levels used to filter the options to be implemented, and the typical best / ideal choice. The solution materialized. The design process is a process between the problem and the desired outcome. During this process, the content of the process changes according to the design principles, designers, and problems to be solved. Although the whole problem starts the design process, when the problem is solved, the problem is redefined. During this iteration, problems are simultaneously replicated from different perspectives into potential development solutions; as to result, the design process is constantly changing.

3.3.1 User-center design methodology

This study will be divided into four parts: user-centered design methodology research method, clearly understand users, tasks and environment to determine user needs; specific requirements; user-centered evaluation-driven and refined product design solutions to solve the whole user experience problem. Adjust the product details from the user's use experience and create the final interactive textile environment prototype for the user.

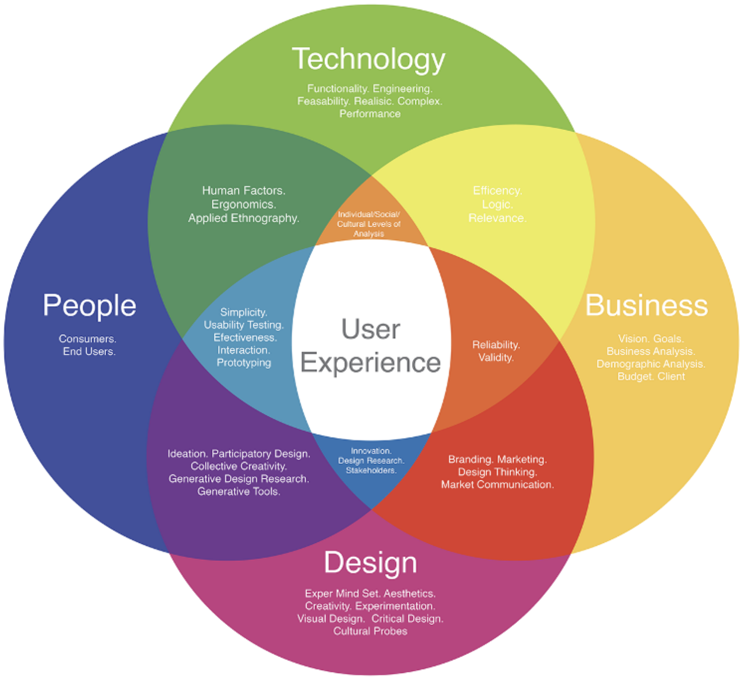


Figure 3.2. user-center design methodology

3.3.2 Rachel Studd's design framework

In Rachel Studd's research design framework, shown in Figure 3.3, as part of the textile design work, the researcher discussed and confirmed the details. For example, the design work begins with confusion and uncertainty. But over time, this can be channeled and clarified.

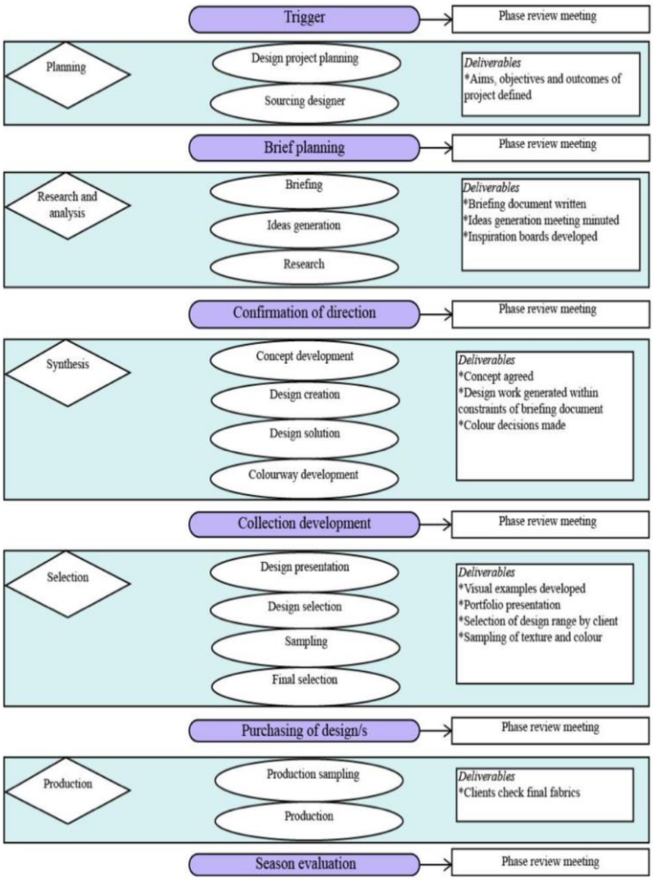


Figure 3.3 Design framework[3]

3.3.3 Baser Design Process Model

Baser has established a design method to manufacture woven fabrics using heavy industrial engineering methods in actual production lines. This method simplifies the complex weaving structure and incorporates the weave ability and size criteria into the computer-aided woven fabric design software.

These methods include 1. Analysis method: A comprehensive analysis of the fabric sample makes the sample retain the copy or the backup data of the modified version. 2. Process method: The weight of simple fabrics can be recorded, including tables, formulas, and other helpful information or standard construction data. Later, it is convenient for designers to delete similar fabrics when designing again. 3. Aesthetic method: It is to design the appearance of fabric through computer[49].

3.3.4 Conceptual design process

Many well-known fashion designers try to bring design elements in different fields, such as integrating architecture, industry, product design, etc. to enrich their knowledge in various fields. They use a variety of media and works to express themselves and expand their methods. These stylish conceptual designers insist on a holistic approach to their collections, including playing a key role in initiating and monitoring design concepts, developing innovative fabrics and their designs and sculptures, and communicating through lively presentations. The survey, based on the design framework shown in Figure 3.4, was conducted by research students who identified similarities between "solutions" and "design" in the design process. 90% percent of respondents said they were involved in the above-mentioned integrated design process stage in the design process, which is indispensable for concept designers. In addition, the close percentage of "solution" (100%) and "solution by design" (94%) denotes an inseparable relationship. It also means you can't design until the designer has a solution to the problem. However, the proportion of "designs" is relatively low (10 per cent), suggesting that designers do not produce designs without a suggested solution. The data shows that the need for the solution of the reference designer or company is the thinking process of the conceptual fashion designer. In the designer's thinking process, "negative evaluation" is as essential as "needs," "inspirations" and "solutions." "Evaluation" is a decision on whether the proposed solution is passed. It also links solutions to "requirements." The correlation between "needs," "inspirations," "solutions" and "negative evaluations" is shown. Negative or positive results of evaluation are conclusions about the strengths or weaknesses of the solution and the strengths and weaknesses expected by the designer, including constraints that the designer considers to be task progress or self-challenge[4].

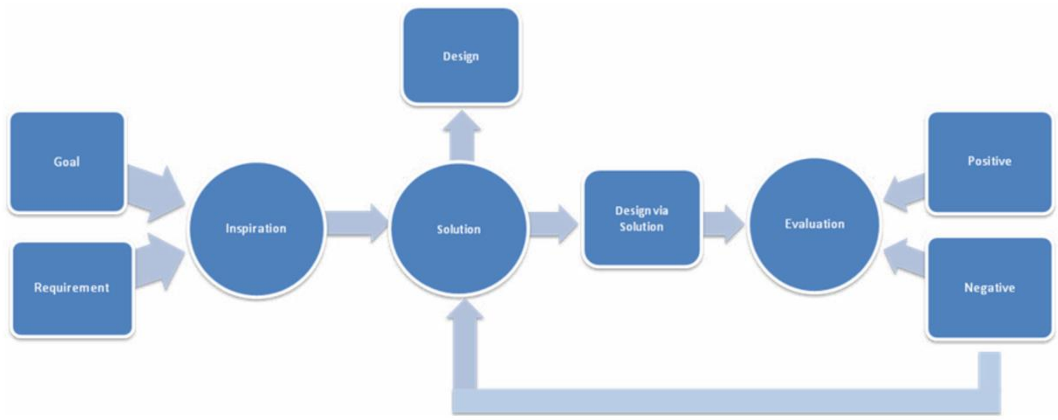


Figure 3.4 Conceptual design process for postgraduate student[4]

3.4 Color psychology in design methodology

In the field of design, Color psychology plays an important role. The methods of using colors, predicting future color trends, and the research and thinking of predecessors in color psychology are summarized theoretically. These explorations start from the psychophysiology, physiological mechanism, and psychological range of colors. These studies inspire the application of art in practice through the clarity, science, and practicality of color theory and promote more scientific and evidence-based design directions [50].

COLOR	MEANINGS AND ASSOCIATIONS
Red	Anxiety, Arousing, Daring, Dominant, Energy, Excitement, Health, Life, Love, Passion, Power, Protection, Spirited, Stimulating, Strength, Up-To-Date
Orange	Abundance, Arousing, Comfort, Daring, Excitement, Extraversion, Fun, Happiness, Lively, Security, Sensuality, Spirited, Warmth
Yellow	Arousing, Cheerful, Confidence, Creativity, Excitement, Extraversion, Friendliness, Happiness, Optimism, Self-Esteem, Sincerity, Smiley, Spirited
Green	Calm, Comfort, Equilibrium, Harmony, Health, Hope, Nature, Outdoorsy, Peace, Prosperity, Relaxation, Security, Serenity, Soothing, Tender
Blue	Calm, Comfort, Competence, Coolness, Dignified Duty, Efficiency, Intelligence, Logic, Peace, Reflection, Relaxation, Reliability, Security, Serenity, Soothing, Successful, Tender, Tranquility, Trust
Purple	Authenticity, Charming, Dignified, Exclusive, Luxury, Quality, Regal, Sensuality, Sophistication, Spiritual, Stately, Upper Class
Pink	Charming, Cheerful, Feminine, Gentle, Nurturing, Sincerity, Soft, Sophistication, Tranquility, Warmth
Brown	Nature, Outdoorsy, Reliability, Ruggedness, Security, Support, Tough
Black	Dignified, Efficiency, Elegance, Emotional Safety, Glamour, Power, Richness, Ruggedness, Security, Sophistication, Stately, Substance, Tough, Upper Class
White	Calm, Clarity, Cleanness, Down-to-Earth, Happiness, Heavens, Honest, Hygiene, Innocence, Peace, Purity, Serenity, Sincerity, Soothing, Tender

Figure 3.5 Meaning and association of colors

3.4.1 Warm Colors and Cold Colors

Happiness and breath (wavelength) are directly related to the amplitude of the warmest long wave, while transport correlation reflects the physical background more directly, because thermal infrared radiation is associated with long wavelengths of red light. Under the action of light, many objects emit intense radiation (e.g., brown, hot iron, rising red sun, etc.) and produce a rich spectrum of long red waves. On the contrary, a lot of things that have to do with cold can appear short-wave blue-green[50].

Warm and Cold Contrast

Hot and cold. Because human life experience and physiological function are closely related to the color of the world, the heat and cold of skin is a reflection of the outside world. Human vision morphed into the feeling of the pilot's skin. They feel warm when they see red, yellow and brown; they feel warm when they see blue, green, blue and purple, they feel cold. White, grey and black may exhibit non-warm or cold characteristics. Magenta and green are fringe colors, depending on the surrounding color, in contrast to the surrounding color. Warm tones are vivid, lively and forward-looking. So, to showcase popular designs, consider using thermal insulation. But keep your eyes warm. It's cool to relax. It gives a sense of serenity. There would be too much excitement. It's fine to be back.

3.4.2 The Kolenda Color Model

Figure 3.6 Color model of Color of Color illustrates the psychological role of color. This model explains how the researcher evaluates a color in this thinking direction[5].

This diagram shows the perceived color by Hue, value, and chroma. This perceived color involves cool color and warm color, these two types of colors then combine attribute color with evaluate color after ending up with a selection of negative evaluation or positive evaluation. Therefore, the color choice matters for the purpose, especially for the choice of a designer.

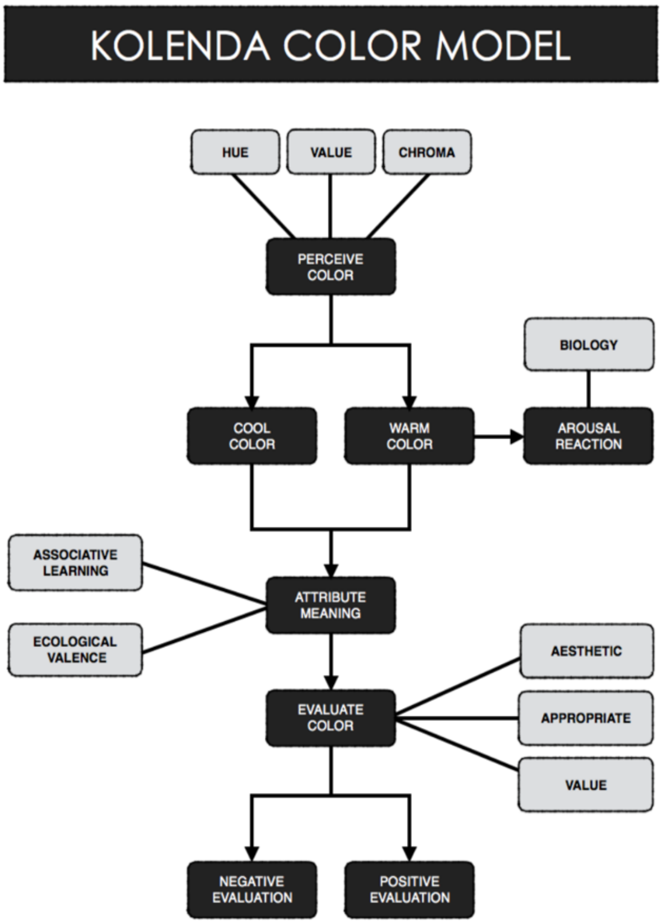


Figure 3.6 Kolenda Color Model[5]

3.4.3 The Munsell System

There are three components in colors: Hue, Value, and Chroma[51]. Hue contrast is the name for all colors. The juxtaposition of different colors, showing the difference of excellent phase, is called color contrast, together with primary color contrast, adjacent color contrast, and similar color contrast between color contrast, the contrast of complementary colors. If these two colors are orange and yellow and have the same red background color, then the bottom red, orange, and bottom red, yellow. Due to the appearance of red, yellow, and red colors after orange bundling, the same component is added to strengthen different parts, so it looks more yellow than used alone.

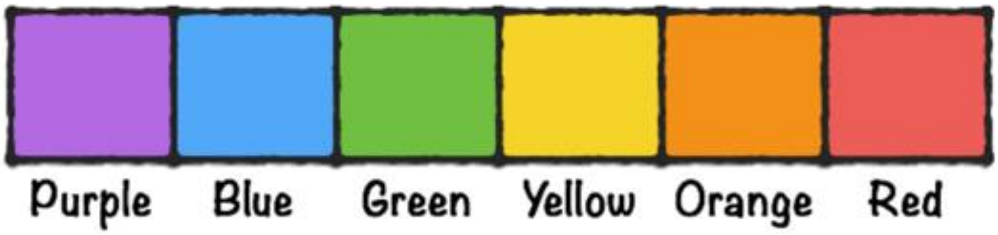


Figure 3.7 Hue contrast[5]

Value is the level of brightness; the low value appears in visual are darker which called "shades" and the high value appears in visual are brighter called "tints".

Figure 3.8 Value contrast[5]

Chroma is the lever of saturation in colour. The higher in chroma more vivid it looks. If the chroma of colour is low, then it will appear as it has been washed out. Yet, value and color are often more important than hue, which is a good thing for marketers.

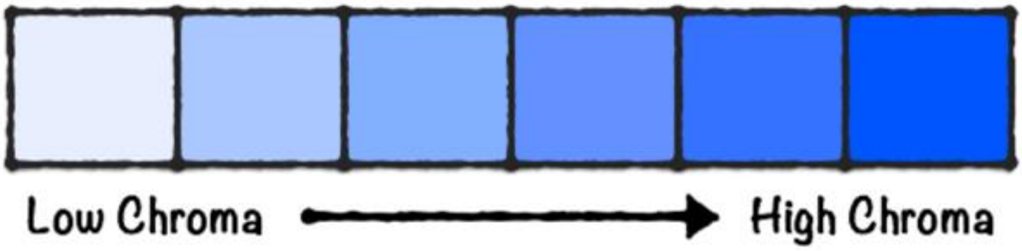


Figure 3.9 Chroma contrast[5]

Why does colour influence us?

Visual senses affect a person's adrenaline, blood pressure, and heart rate through color. These physical states will make you more energetic or vice versa. Research has shown that warm colors can increase a person's response to excitement. You will feel more exciting[52]. In addition to arousal, another response is evaluative: Does the wearer "like" these? Crowley (1993) discovered a positive linear trend between evaluation and color wavelength. People prefer colors with shorter wavelengths.

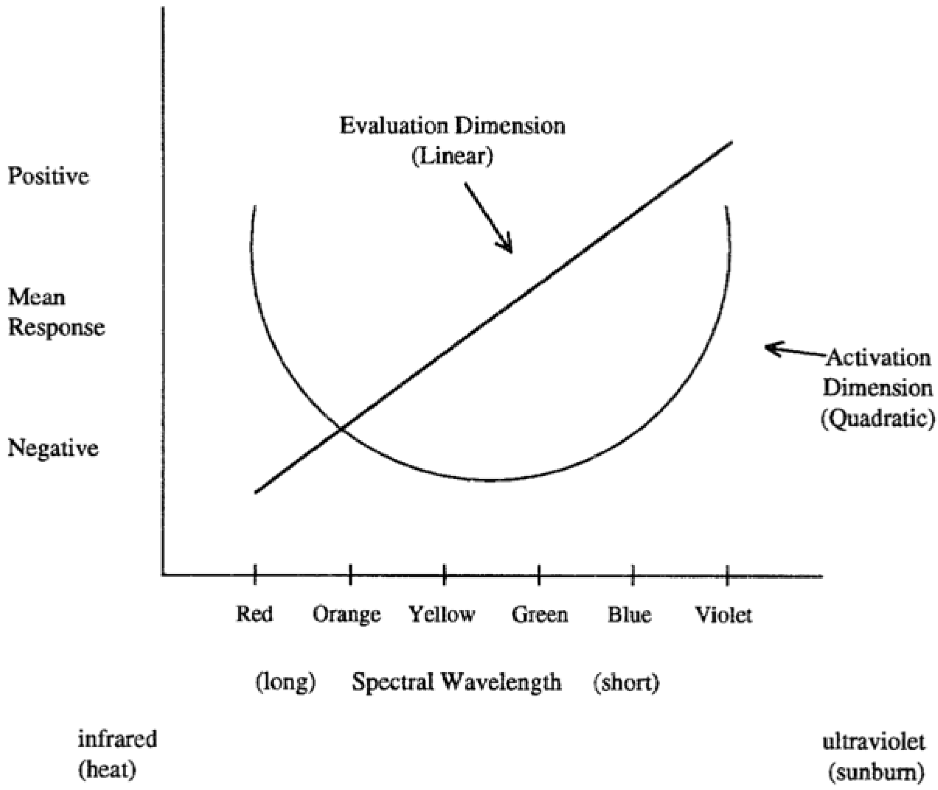


Figure 3.10 Arousal vs. Evaluation

3.5 Development of Theoretical Design Process Model for Interactive Textile Equipment

The comprehensive and critical literature review is the beginning of interactive textiles device creation. Understand the different design processes in the market, performance, design, technology, etc., then propose the user-center methodology to adopt forward. The user-center design methodology method was divided into four parts, clear understanding of users, tasks and environments to identify user needs; specific requirements; product design solution; to be promoted and refined through user-centred evaluationc and to address the entire user experiencec. Finally, the prototype of interactive textile devices adjusted the product details from the user’s use experience and created the final interactive textile environment prototype for the user.

3.5.1 Needs

Identifying and exploring needs

Users, tasks, and environments had to be understood to determine user needs and determine product positioning. “The design of any product or service must begin with a complete understanding of the customer’s needs” [53]. Reviewing the latest interactive textile devices in the market and the technologies and applications related to interactive textile design (e.g., various LED lights, sensors, and fabrication methods) helped us identify the user's demand for interactive functional textiles in the current product.

3.5.2 Problems

Analysis problem

The design process model emphasized the importance of analyzing and determining problems. The literature points out that although the problem analysis step may not be significant, it is a crucial step in the overall design and production process [54]. Analyzing problems can improve understanding of goals and explore the relationship and patterns between problems and goals [55].

Statement of problem

This step aimed to identify the necessity of interactive textile environments for the growth and development of toddlers and its value as a product design and production. We identified existing problems and determined whether there was value in overcoming and optimizing them. “The analysis is a small problem but important part of the overall process [54].” Thus, we evaluated, improved, optimized, and communicated design specification requirements to subsequent manufacturing or integration steps as soon as problems had been identified.

3.5.3 Conceptual design

This research design step focused on the following points: a safe environment, suitable colors for young children, interactive methods, different sensors, weaving techniques, and integration methods.

3.5.4 Development of initial prototype

The process at this stage reflects the shaping of the design concept. After detailed research, suitable samples were selected from these preliminary samples [54]. Specific sensors, LED lights, controller, speaker, and the wool-fabricated surfaces of the play mat using the tufting technic were defined as initial prototypes. Those unsatisfied steps were adjusted later in the final stage. The developed prototypes were as follows:

1) Fabrication of electronic yarn with various types of wrapping and core yarn by the self-development spinning machine of electronic yarn. These selected spinning and core yarns are 210D PE, 210D PET, and 210D Nylon-6. The experiment was applied to select the best yarn;

2) Three fabricated the embedded fabric prototypes with electronic yarn were tested through a handwashing experiment;
3) Two shoe uppers were developed using a knitted machine and a zigzag sewing method;
4) Laser-cut panels were employed for electronic yarn attachments with a customized battery;
5) Three prototype tufting play mats were developed with 100% “milk cotton wool” and integrated with various sensors, LED circuit boards, speakers, and controllers.

3.5.5 Evaluation

The evaluation process was the critical step in the concept development process after the initial prototype had been completed. The evaluation criteria were based on the expected designer's preset interactive carpet technical characteristics for evaluation. There were two main evaluation parts: electronic yarn and an interactive textile play mat. The researcher decided after the evaluation whether to continue the concept.

The researcher implemented the electronic yarn evaluation method by testing the electronic yarn with related experimental machines, such as force testing/tensile/bending and washability. Then, we did a comparison trial test between commercial play mats and interactive play mats by toddlers. The teacher used a related questionnaire to observe the toddler's behavior, and we and evaluated the prototype using the data.

3.5.6 Solution

After the evaluation, designers determined the characteristics of different samples and made modifications based on the results. Designers had to reflect on and address technical and functional requirements. This is a skill that designers had to cultivate. Then, they found suitable solutions based on the problem and made modifications.

3.5.7 Details design

This was the final stage of the design process after initial sample testing and refinement, and the establishment of the final prototype could be determined. Finally, the electronic yarn design collection and interactive textile play mat for toddlers was created.

3.6 Summary

Practical research way and user-centered design methodology were used in this study. The researcher included the accuracy of knowledge derived from a series of design cycles and integrated relevant literature to show the design methods to help product development, including product structure design ideas and color selection methods. All of the knowledge is organized in a system, and it is challenging to explore and reflect. Researchers checked and solved the problems of product prototyping through systematic reflection. The product development started with electronic yarn with a self-developed wrapping machine, then moved to experiments by testing various performance steps as the evaluation process, and then fabrication of electronic yarn collection, and we used the same methodology to fabricate two shoe uppers.

Further, researchers have used some methods to develop interactive textile play mats for toddlers. Finally, the interview and questionnaire to complete the entire research project are described.

Chapter 4 Development of electronic yarn and fabrics

This chapter introduces the research work of the research team by detailing its goal of "developing and creating the softest and most refined electronic yarn." The research work included market research, appearance, yarn structure, performance, production, and testing of electronic yarn. Based on these works, it was also necessary to consider the softness and size requirements of the target final product and to select appropriate winding yarns, winding methods, performance testing, design product color stories, inspiration sources, applications, market demands, and final sample production. This research project introduced the research process and results through relevant experiments. Finally, this chapter summarizes the research findings of the researchers in this project. The researcher presented the final electronic yarn sample collection and the prototype of shoe uppers made of electronic yarn.

4.1 Design rationale

Here, the researcher presents all of the processes of design development, which began with the electronic yarn design, development, sampling, experiments, test results, and prototype finalization. The design framework steps show the collection of inspiration, starting from the planning stage. First, the development of product construction technology included the structure, materials, technical thinking, and combination methods. Afterward, the process and experiments were repeated using the practical research methodology until the goal was achieved. In the model of thinking, we refer to a cyclical research methodology.

4.2 Design and fabrication of electronic yarn

4.2.1 Theme inspiration and color story

The design inspiration came from the demand for the combination of wearable technology and fashion trends in daily life. The electronic yarn collection was inspired by the trend book Earth Alchemy 2020; it represents a new fusion of man, nature, and technology. It was developed and inspired by four concepts: crystallized, culture clash, split gill, and bio dome. In those four different directions, the different types of sample yarns were designed. Below is the recent work of the design theme boards with a color story.

Figure 4.1 Design theme boards with colour story

4.2.2 Target market

People are now dissatisfied with fast fashion and desire high-quality, long-lasting products that reflect their personality. Personalized customization, special occasions, uniqueness, gifts, and special meanings represent keywords for this target group. The target group aims for all ages and genders that demand high-quality living. They would rather buy less so that they can spend their money on high-quality items. They choose products that are meaningful and functional. Thus, researchers conducted a questionnaire involving 100 people, spanning different genders and ages (18–70 years). Here, 65% of people reported being willing to pay more for higher-quality clothing and being interested in wearable technology.

4.3 Fabrication of electronic yarn

In the design of wearable functional electronic textiles, in addition to the functional and technical issues, the biggest concerns are comfort, safety, and beauty. Existing electronic yarn products have been widely used in various fields. Still, electronic yarn usually has shortcomings, such as poor washability, roughness, hardness, poor flexibility, airtightness, and discomfort. In addition to combining technology and aesthetics, the design needs advantages such as softness, comfort, lightness, breathability, and washability. To ensure that electronics survive in soft and comfortable yarns, we must consider the critical points of precision, softness, and small internal electronic components. Therefore, in this study, design started from these aspects. Below, the researcher describe the recent work of the experimental wrapping process of the electronic yarns developed.

Here, the researcher employed a 1.5-mm inner-diameter syringe rius-mc with four locking needles. In the preliminary experiment, the researcher tested whether the machine is suitable for processing electronic yarn, including the actual problems in the effect manufacturing. The tubular warp knitting structure (knitting sleeve) is made of multi-filament deformed polyester yarn (150 dtex / 48). A schematic diagram of the relevant manufacturing concept is shown in Figure 4.2, which shows the plan of the core yarn and four polyethylene (PE) yarns [6].

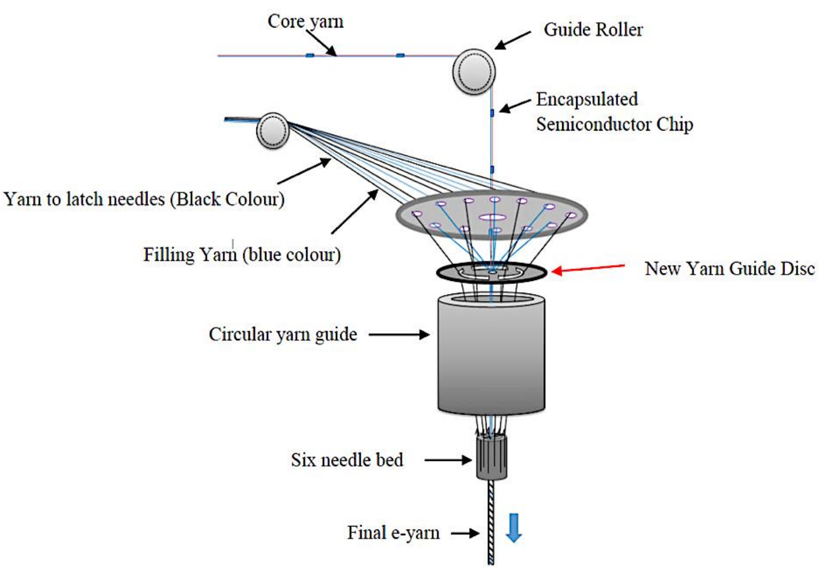


Figure 4.2 The yarn circular warp

According to the reference above, the spinning machine was designed in the research group for the wrapping process in this research, which is shown in Figure 4.3.

Figure 4.3 The spinning machine of the electronic yarn

The experiment's early-stage plan started with the preparation of simulated electronic yarns, shown in Figure 4.4. The equipment and tools included an electric soldering iron, tin, copper conductive tape, aramid paper, or PI film. The simulated electronic yarn core is shown below; it matches the ideal size of the selected electronic yarn core for the subsequent wrapping test progress.

Figure 4.4 Simulate electronic yarn core with Aramid paper

The wrapping structure of the electronic yarn is shown in Figure 4.5: (a) Method 1:

FCBA-Core yarn+ wrap yarns (v); (b) Method 2: FCBA-Core yarn with carrier yarns + wrap yarns (v). Both designed wrapping structures exist in the subsequent process.

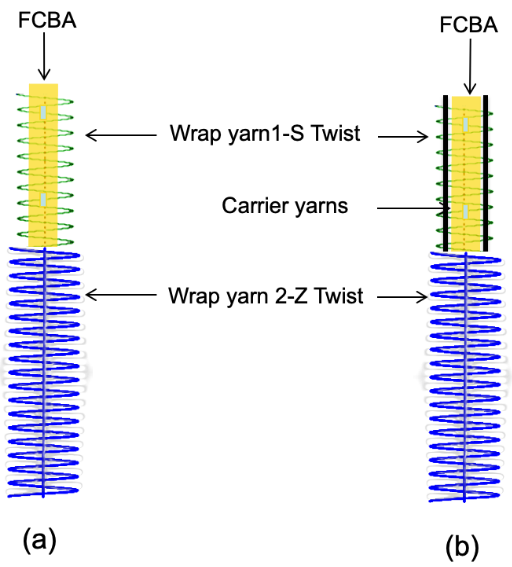


Figure 4.5 Structures of the electronic yarn a and b

Figure 4.6 shows the stimulation yarn structure in a 3D design view in the initial prototype stage.

Figure 4.6 Stimulate yarn structure in a 3D design view.

Figure 4.7 below shows the manufacturing process with a fiber-based circuit board assembly (FCBA). This yarn production process was mainly completed by a spinning machine designed and invented for this project. This machine's method of making electronic yarn was mainly interpreted as three steps. One is the input system, which feeds FCBA and core yarn into the feeding tube together. The second step is the wrapping system. The machine wraps these decoration yarns (cover yarn) through the S and Z parts to the outer layer of FCBA and core yarn. The third step is the output system. The wrapped electronic yarn is output through the output roller. The control board can manage the entire process in the figure to control the speed and adjust the density of the yarn.

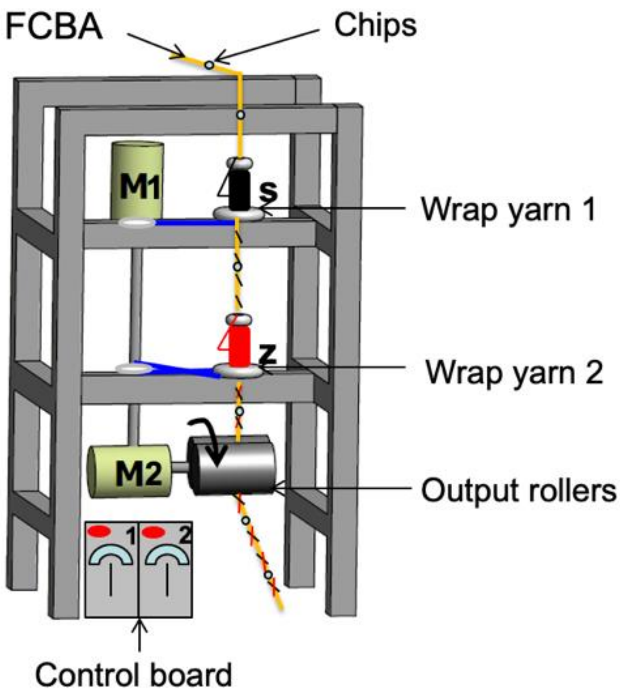


Figure 4.7 Spinning system of the electronic yarn

Finally formed, the stimulated electronic yarn is required, as shown in Figure 4.8 below. This result confirms that the wrapping process for electronic yarn is approved. The decoration (cover yarn) can be any color in the later design stage after the evaluation.

Figure 4.8 Stimulate electronic yarn for systematic testing

4.4 Evaluation of electronic yarn

Further development with the same method of the spinning system for electronic yarn according to the theme and color pallets was done, all of the FCBAs were developed on PI film, and the LEDs type were size 0402. Three parts confirmed the electronic yarn structure: FCBA, core yarn, and cover yarn.

Core yarn

The core yarn was placed between the cover yarn and FCBA (fibrous circuit board assembly). It plays a role in sharing the pulling force. The ductility of the core yarn should be lower than that of the FCBA component yarn. When electronic yarn suffers from deformation, the core yarn will bear the load and limit the axial stretch deformation. The force acting on FCBA will be dispersed, and electronic yarn will not be damaged. The cover yarn should be not only tensile resistant but also delicate, considering that the finished diameter of electronic yarn is 1 mm. Thus, the size of the central load-bearing yarn could not exceed 1 mm in diameter. In fact, on the premise of strength requirement, the finest core yarn would be selected. Comparative experiments on the tensile strength and size of several yarns were conducted. The final product aims to be a robust, soft, and fine electronic yarn with a diameter of less than 1mm. Three kinds of yarns were considered for further experiments: 210D PE, 210D PET, and 210D Nylon-6. The goal was to find a carry yarn that could carry the FCBA when warping progress to share the pulling force and increase the strength of the yarn. The final composite fibers identified were 210D PE, 210D PET, and 210D Nylon-6, which are characterized by their softness, high adhesion, high strength, and lower elongation.

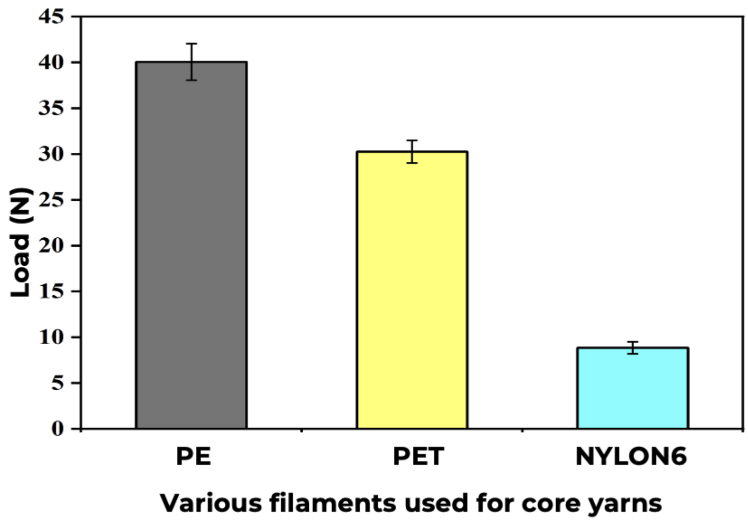


Figure 4.9 Force testing

Preparation: Standard condition; Room temperature, 20°C; Humidity 65%.

Sample specifications: 210D PE, 210D PET, 210D NYLON-6

Test apparatus**:** Instron 5944

Testing parameters: 250 mm/min

Gauge length: 250 mm

Results and discussion: Figure 4.9 shows that the yarn type 210D PE showed the strongest load force at the break. Five repeated tests were conducted for each type of yarn. The tensile testing parameters were established according to the ASTM D2256 standard for Tensile Properties of Yarns using the Single-Strand Method. The various filaments 210 PE were chosen to be used for the final core yarn.

Cover yarn

The cover yarn was a decorative yarn used to wrap corn yarn and FCBA. The outer wrapping yarn was mainly selected for its design appearance and purpose. The yarns selected here were divided into A and B. Concept A was a basic style with a natural white color only. Concept A was chosen because the texture of this particular yarn (Figure 4.10) could be wrapped as the cover yarn evenly. In addition, it could be dyed in different colors. More possibilities could be designed and created according to different market requirements.

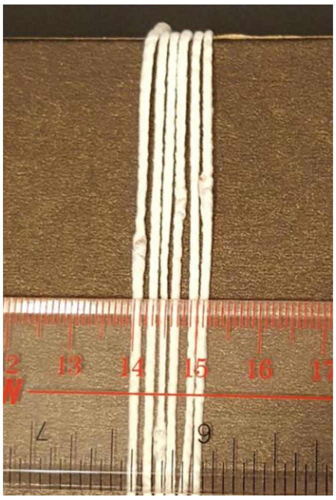


Figure 4.10 Electronic yarns using 210D PE core yarn and concept A cover yarn

Concept B was the decorative-style yarn collection designed based on current trends and colors. This collection developed into four design stories. Each story chose different cover yarns to complete a decorative look-book. The designer also designed and produced five different kinds of electronic decorative yarn for each story. One of the cover yarns in each story was selected to design and produce a sample fabric swatch, as shown in Figure 4.11.

Figure 4.11 Electronic yarns using 210D PE core yarn and concept B cover yarn

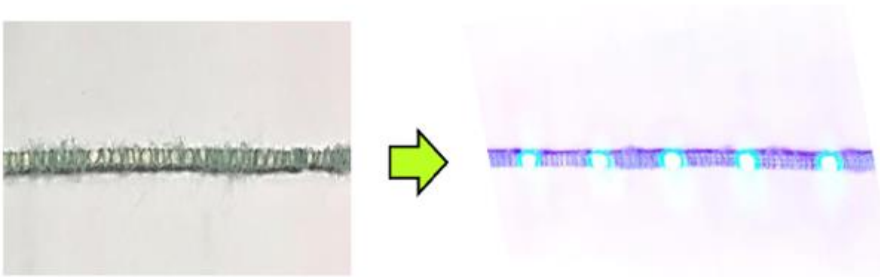


Figure 4.12 Lights on testing

The lights-on testing electronic yarns using 210D PE core yarn and concept B cover yarn are shown in Figure 4.12. A few more experiments were done to test the electronic yarn by tensile properties and bending properties for comparison with the exited commercial yarn.

Tensile properties of electronic yarn

Three distinct electronic yarns—E-yarn-1 (employing the 0201 LED FCBA strip), E-yarn-2 (employing the 0402 LED FCBA strip), and E-yarn-3 (employing the 0603 LED FCBA strip)—were fabricated by combining three varieties of FCBA strips with 210D PE serving as both the core and cover yarns. All three types of electronic yarn belong to the experimental group, differing primarily in the FCBA strips they incorporate. This experiment used the following machines: Instron tensile 5944 and Keithley 2400. The preparation was in standard conditions, at 20°F and 65% humidity. The sample specifications were 1 mm wide and 14 cm long. The test apparatus was Instron 5944. The testing parameters were v = 5 mm/min, gauge 13 cm. During the tensile process, all of the LEDs of the electronic yarn were light. When the electronic yarns were broken, the LEDs turned off. The average tensile property of electronic yarn was over 40(N), much stronger than the existing commercial electronic yarn, as shown in Figure 4.13.

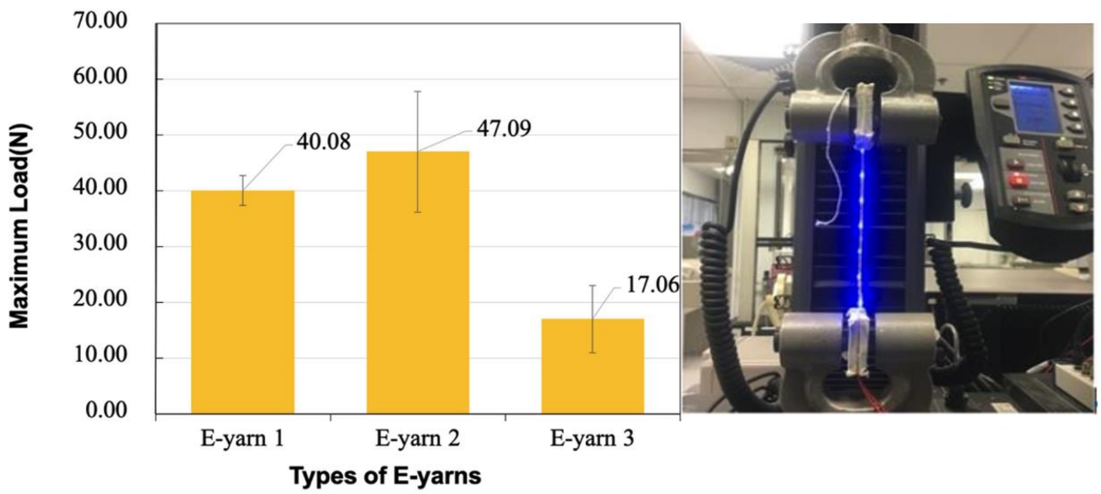


Figure 4.13 The tensile property of electronic yarn

Bending test of electronic yarn

This experiment used a KES-FB SYSTEM machine to complete the bending test.

Table 4.1: Comparison of bending rigidity of commercial electronic yarn and electronic yarn with FCBA

Sample	**Bending rigidity of Commercial electronic yarn (**gf*cm^2/yarn**)**	**Bending rigidity of Electronic yarn with FCBA (**gf*cm^2/yarn**)**
1	4.5628	0.3416
2	4.3432	0.4759
3	6.6368	0.5975
Mean	**5.18**	**0.47**
STD	1.18	0.13
CV	**0.23**	**0.27**

NOTES:
B1/B2= 10.98

The preparation was completed in standard conditions, at 20°F and 65% humidity. Sample specifications were as follows: commercial electronic yarn and electronic yarn with FCBA. The instrument was KES-FB SYSTEM. The bending rigidity of commercial electronic yarn was over 10 times harder than that of electronic yarn with FCBA.

4.5 Design and fabrication of fabrics with electronic yarn

Given that the technology is feasible, Figure 4.14 shows the weaving structure of the embedded electronic yarn in a textile structure.

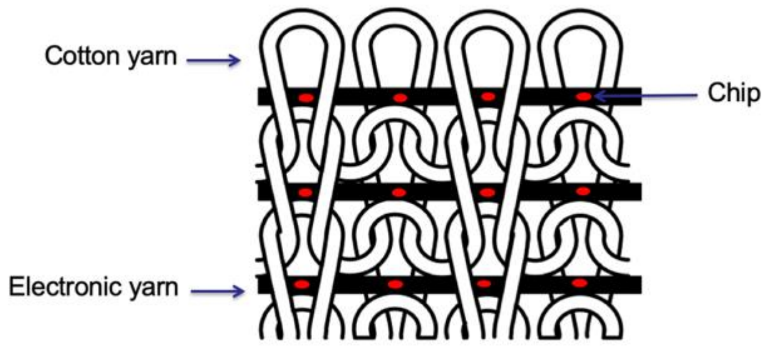


Figure 4.14 The knitting construction with electronic yarn

The process below involved knitting samples embedded with electronic yarns by using the knitting machine by WEALMART (WM-01-6766). As the length of the electronic yarn was limited, this was a suitable machine at this stage.

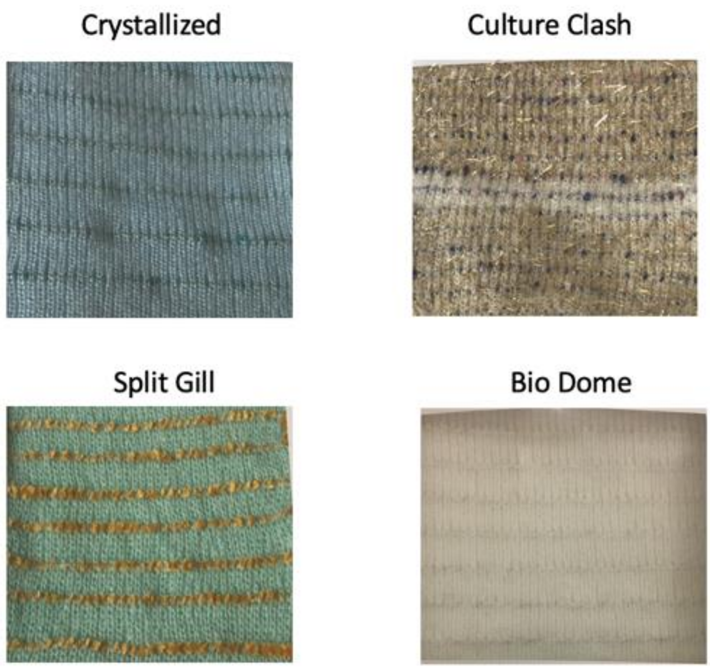


Figure 4.15 The embedded fabrics with electronic yarn

Figure 4.15 shows the samples of embedded fabric with electronic yarn, which was designed according to the mentioned design directions; as the length limitation, the plain knitting method has been chosen for the stage.

4.5.1 Handwashing test of fabric made by electronic yarn

The washing test referred to the AATCC Lab Program 2-2018 "Home Wash: Hand Wash," developed by the AATCC Committee RA88 in 2018 (replaces Monograph 5). The preparation was completed at the following washing temp, rinsing temperature, and designation °C (°F) °C (°F)： Cold 27 ± 3 < 29. We added 7.6 ± 1.9 L of water at this temperature to the wash tub. Then, we added 20 ± 1 1993 AATCC Standard Reference Detergent to bath. According to the AATCC laboratory procedure 2-2018 experimental conditions, the proportion was reduced by four times. Then, 8 L of water was mixed with 20 g of washing powder. In this experiment, the proportion was changed to 2 L of water with 5 g of washing powder. Water temperature was set at a wash temp, cold 27 ± 3 rinse temp, < 29. Samples were prepared and named 1, 2, and 3. Each sample was knitted with two electronic yarns.

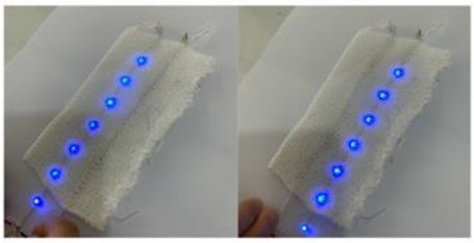
Figure 4.16 Washing testing process

Finally, the researcher performed the lights test for brightness on March 31, 2020, at 10:00 a.m. The room temperature was 22°. The result showed that all of the electronic yarns were working well at 5 days after the washing test. This result confirms that the washability of the electronic yarn is much better than that of the existing commercial electronic yarn. Figure 4.16 shows the washing progress. Table 4.2 reflects the time record. Figure 4.17 shows samples 1, 2, and 3 after the wash test; all of the LED light chips were fully occupied.

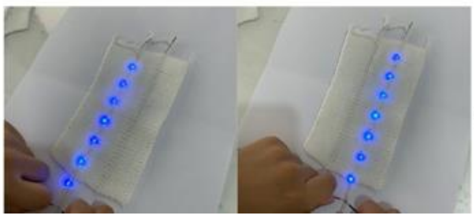
Table 4.2 Time record

Items	Date&Time	water temperature	Room temperature
Sample 1& 2	25th March 2020,9p.m.	25 ℃	24 ℃
Sample 1& 2	26th March 2020, 5:20 p.m	24.5 ℃	25 ℃
Sample 1& 2	27th March 2020, 6:55 p.m.	24 ℃	25 ℃
Sample 1& 2	28th March 2020, 7:00 p.m.	26 ℃	26 ℃
Sample 1& 2	29th March 2020, 6:00 p.m.	24.5 ℃	25 ℃

Sample 1



Sample 2



Sample 3

Figure 4.17 Sample 1, 2, and 3 LED light chips fully occupier

In summary, the above experiments showed that the structure and performance of the electronic yarn designed with the researchers' participation met the project's expected parameter requirements. The structural design approach reinforced the weaknesses of the original electronic yarn. However, more possibilities exist for future development in the design of electronic yarn products.

4.6 Prototype shoe upper with electronic yarn

The fashion shoe upper was designed and developed through the design concept of the crystallized topic, which was influenced by the trend book Earth Alchemy 2020. The primary shoe upper is made of 100% polyester. The machine used was the Knitting machine CMS822. Interlock stitch was the knitted structure method. The decorative pattern was embroidered with electronic yarns by the TAJIMA embroidery machine. Figure 4.18 shows the color story of the shoe upper collection.

Figure 4.18 Color storyboard

After many samples and experiments, the shoe uppers shown in Figure 4.19 and Figure 4.20 below were chosen as prototypes for the project plan, and the user controls the vamp through the LED switch. In the next step, the researcher considered different applications for future design directions.

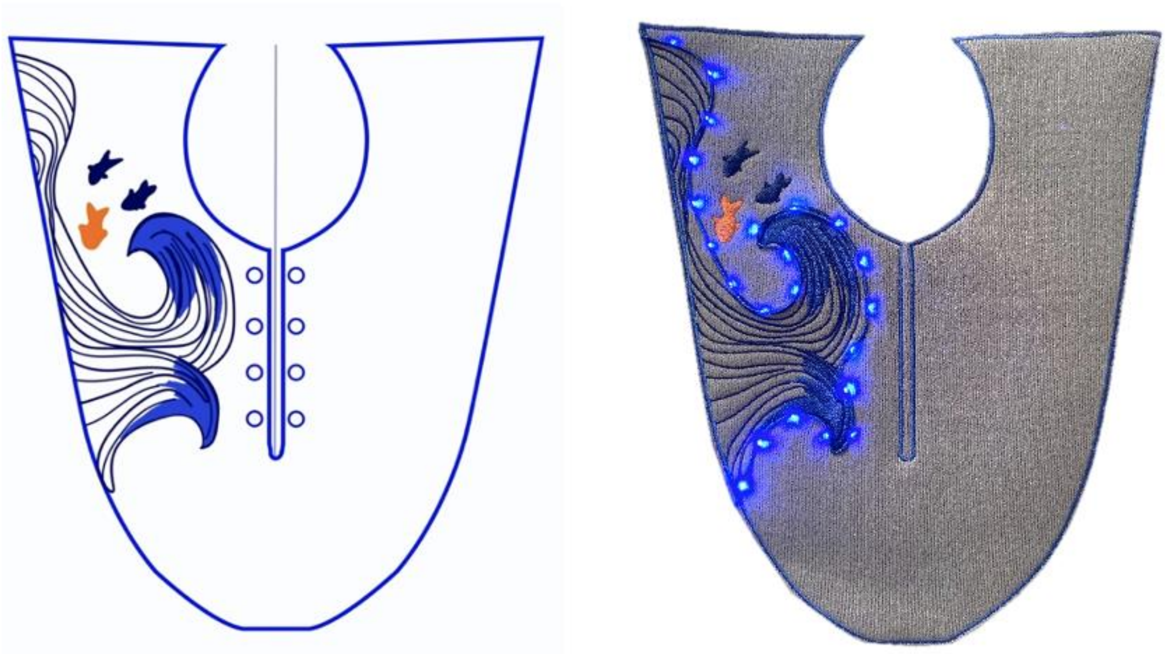


Figure 4.19 Shoe upper 1(left is the illustration, right is the final product)

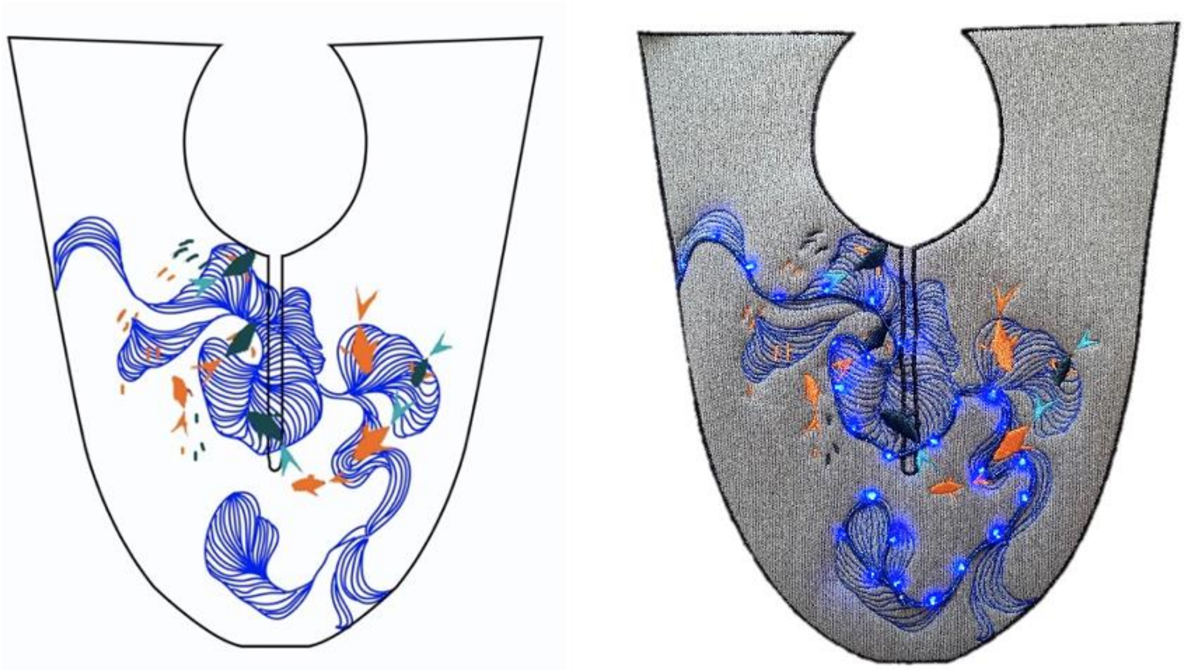


Figure 4.20 Shoe upper 2 (left is the illustration, right is the final product)

4.7 Reflection

The experimental results indicate the progress in the preparation process of electronic yarns and the completed photonic shoe upper. The design process started with understanding the market trends and social needs and setting goals and ended with selecting the best manufacturing method for the shoe upper through experiments. In this chapter, various experiments were included, laying the foundation for the final design and production of the product. The shoe uppers are lightweight, flexible, wearable, fashionable, and highly suitable for carrying electronic yarn, showcasing the advantages of optoelectronic yarn. The researcher aimed to continue challenging user-centric design methodology to create meaningful and flexible glowing interactive products that are fashionable and enhance human life. Therefore, continuing to adopt a user-centered perspective and focusing on toddlers as users, she designed this photoelectric interactive play mat set that supports their development based on this user group. Consequently, the relationship between the shoe upper and the evolution of interactive gaming mats represents a comprehensive progression in design journal development from yarn development to prototype fabrication. The design, experimentation, and production processes guided the research to develop a unique design framework. There is not much systematic design research methodology in the fashion design industry, which is mostly story-based; in my opinion, my work could be an example to help people who want to challenge or involve interdisciplinary research in their research work. Furthermore, through these experiences, researchers designed and applied for a patent for “Microelectronic Yarn Accessory Trims and Production Conference, ZL 202010332371.5.”

Chapter 5 Development of Interactive Photonic Play Mat

This chapter introduces the entire process of researchers designing and developing a children's photoelectric interactive play mat, including the design theme, color story, material selection, product design drawings, production methods, user group positioning, circuits, product structure, interaction methods, programming, application scenarios, explosive diagrams, 3D diagrams, and function tests of the final product. In terms of the thinking mode, it refers to a user-centered design methodology. The evaluation method was an experience survey questionnaire based on user feedback and observation of trial results by teachers and optimizing the product to achieve users' desired product usage goals.

5.1 Design Rational

The prototype ideas were inspired by the development and production of electronic yarn in Chapter 4. The design rationale of optoelectronic textiles can be used for a more meaningful design direction. In addition to the attractiveness of appearance, researchers are now focusing more on the functionality of products to upgrade the quality of life. Targeting the needs of selected user groups, we extended the design and production of optoelectronic interactive textile products.

5.2 Design of interactive play mats

5.2.1 The theme

The researcher discovered that toddlers today start to use electronic entertainment devices, including tablets, smartphones, or iPads, in early childhood for various reasons, including parents' busy lifestyles, a lack of companionship, or parents' need for children to be quiet in public. However, prolonged use of electronic tablets or other small-screen devices results in less time for physical exercise, which can lead to health hazards, such as prolonged inactivity while watching screens, a lack of movement, loss of interest in the real world, and decreased vision [10]. The research started with the crucial role of early education in toddlers. As mentioned in Section 2.4, the most critical period of brain development in a child's life is before 6 years of age. However, in this era of rapid technological development, few interactive toys on the market are suitable for children aged under 3 years, and none of the products meet free play concepts or offer interaction photoelectronic functions. Therefore, the researcher designed a play mat for toddlers that is safe and fun, with optoelectronic interactive functions to apply for free-play games. A sensation training system embedded in the mat offers interactive music and optoelectronic technology when children come into contact with the textile surface. Training children's growth sense, including the question-answering voice module mentioned in the relevant literature on cognition, can stimulate toddlers' interest and actively help them explore and meet their daily playtime needs, providing opportunities for physical and mental development. Finally, the researcher evaluated the value and practicality of the product in a kindergarten cooperation trial project and made final adjustments accordingly.

5.2.2 Target market

Preschool children are the primary target users, but the consumers who purchase this product are their caregivers, such as parents, grandparents, and buyers of kindergarten products. The product's appearance was inspired by a mother's love, demonstrating the posture of hugging and caring, from mother to children. The rich colors create a sense of security, providing a good vibe for toddlers to learn through play. The soft textile characteristic makes it easy for kindergarten or other indoor users to fold or roll up the mat for storage. It is superior to traditional electronic toys, which are often rigid, overly large, and inconvenient to store. The soft surface is also more friendly to toddlers who are not proficient in running and walking.

5.2.3 The competitor

The competitor collected responses to online questionnaires in group chat in the "WeChat" group named "The Popular Baby Crawling Carpets for Mothers in China in 2023." The recommended play mat structures are classified into three types (i.e., folding, rolling, or puzzling), and the thickness size is 2–4 cm. A thickness of less than 2 cm is not recommended, as it is not as comfortable or safe for toddlers. The materials are mainly PVA and PE+PU. The commercial play mat for toddlers in the market offers protection only, although a few have extra game patterns on the surface, which may be an extra game function that allows children to play simple games with assistance from an adult through spoken instruction. Compared to the traditional commercial play mat, the developed play mat targets the goal of the model of autonomic play under the interactive photonic environment for toddlers. It combines photoelectric and voice module interactive functions that allow toddlers to spend more time on large movements and to enhance their cognitive abilities. Therefore, toddlers can achieve the learning purpose through play. Figure 5.1 shows the recommended commercial play mat structures.

Fold	Roll	Puzzle
 4cm (depth)	 2cm (depth)	 2.5cm (depth)

Figure 5.1 Recommended commercial Playmats

5.2.4 The color story

As mentioned in Chapter 3.1.3, the researcher incorporated color psychology into the design process. Happiness and tone (wavelength) are directly related to the hottest temperature range colors in the long wave, while transmission is more directly related to the physical background. In contrast, many cold-related objects appear in shortwave blue or green. The color and psychology table in Chapter 3 indicates that yellow and orange visually give children a sense of joy and warmth, which increases their sense of security and reduces their vigilance and prevention. The pink color scheme evokes a desire for communication among children, making them feel relaxed and joyful. It also symbolizes a mother’s love. The natural wood color relieves tension and distress in children's emotions. The green style evokes a sense of spirit, freshness, and naturalness. The red, gold, and magenta are exciting and can be used to encourage and bolster the confidence of shy children. Finally, cool colors, such as blue, purple, gray, and black, are not recommended for children to use, as they may feel oppressive. So, in this child-centered user perspective, the researchers used 60% pink, 10% purple-pink, 5% red, 5% yellow, 5% green, 5% orange, 5% blue, and 5% wooden color in the color board. The collage in Figure 5.2 shows the color board inspiration with the selected colour palette.

Figure 5.2 Colour storyboard

5.2.5 Fabrication method selection

Idea 1: Laser-cut commercial fabric

The starting point was continued from the electronic yarn design idea from Chapter 4. The researcher considered unlimited connection panels with electronic yarn attached to the surface, with an interaction sensor function supported underneath. Figure 5.3 shows the laser-cut fabric panels prototype.

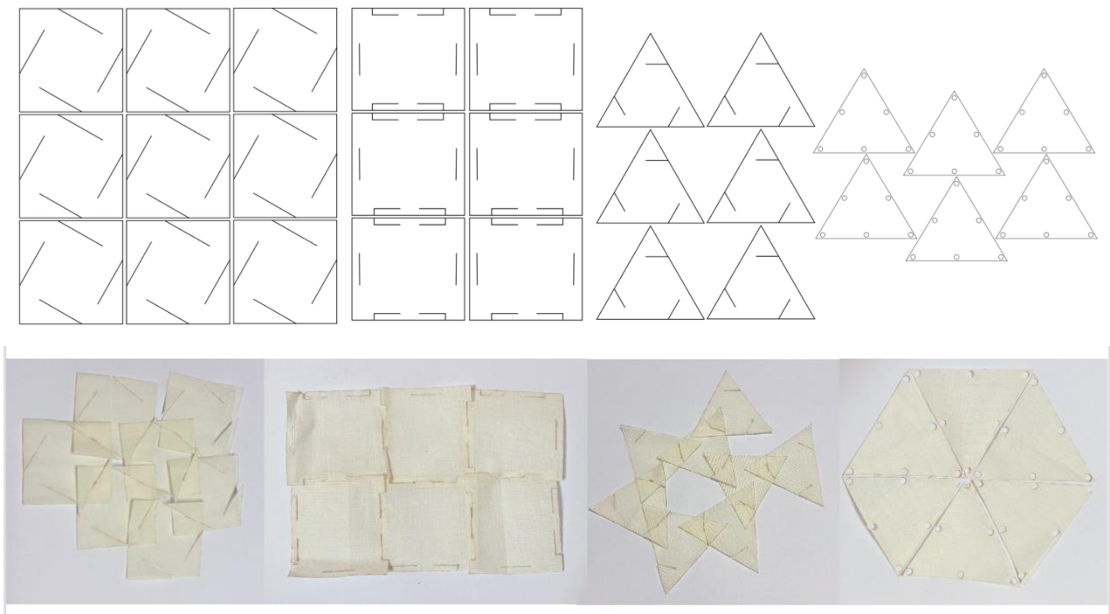


Figure 5.3 Laser cut designs and samples 1, 2, 3, 4

The technical drawing of the design idea is shown in Figure 5.4. The design of No. 3 was adopted for further development.

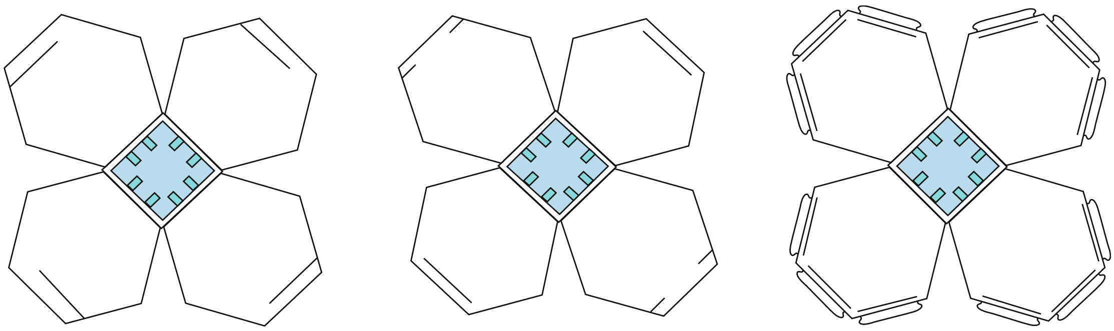


Figure 5.4 Technical drawing of extensional panels 1, 2, 3

Figure 5.5 shows the construction idea of fixing the battery and sensor in the middle part of the panels. The electronic yarn is placed on top. The size of the snowflake panel is around 5 cm in diameter. Each side has a connecting point that can be connected at any angle to create any size or shape the user desires.

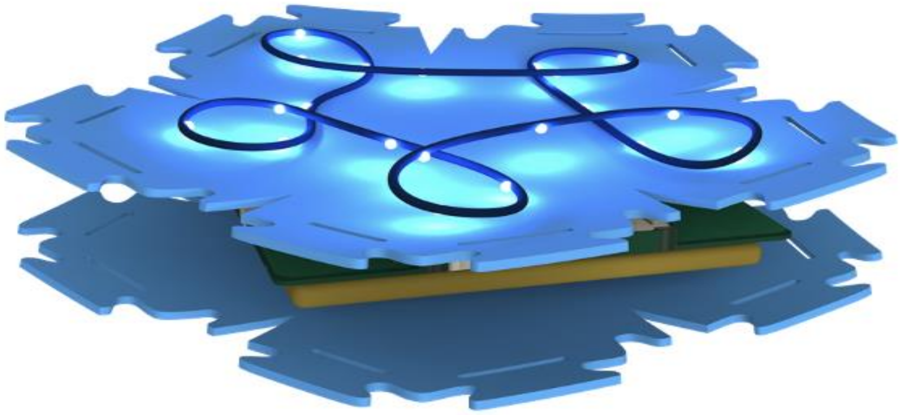


Figure 5.5 Construction 3D look with battery

Figure 5.6 shows the sample of electronic yarn connection panels connected with a battery with five sets of snowflake combinations. Each specially designed battery allows eight electronic yarns to be connected. The left image shows when the battery power is off; the right image, when the power is on.

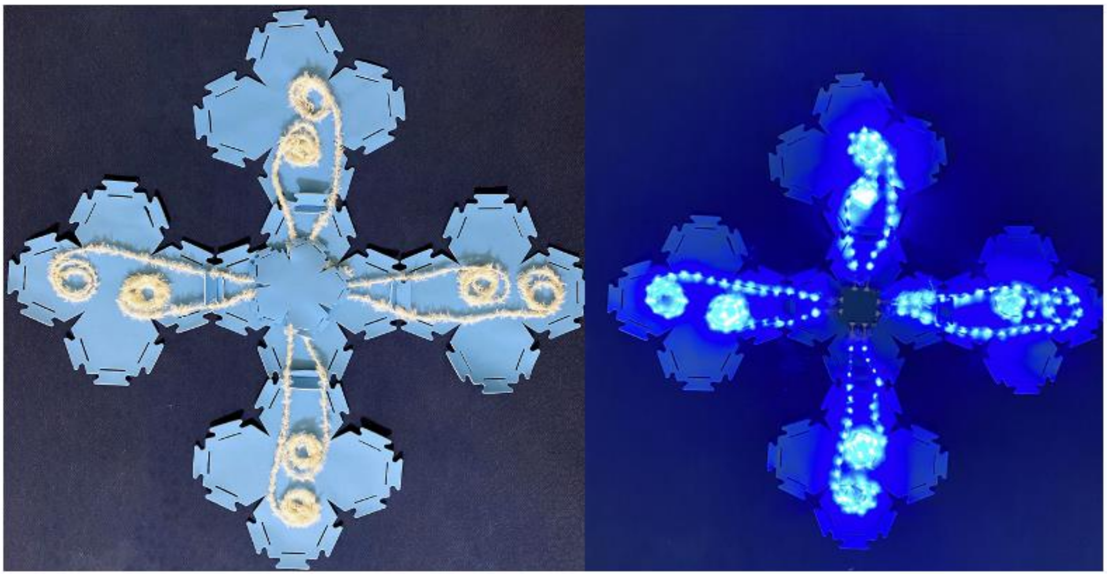


Figure 5.6 Electronic yarn connection panels

A specially design battery set for electronic yarn for this project is shown in Figure 5.7.

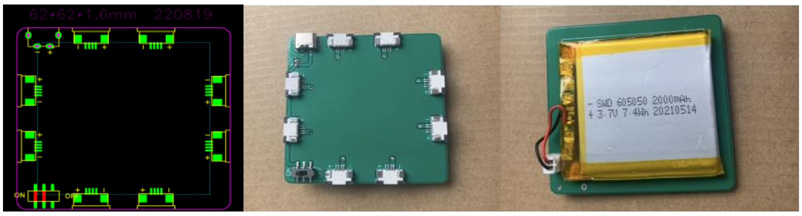


Figure 5.7 Battery circuit design and sample look set front and back

This idea was eventually abandoned because it referred to the safety requirements regulation for children's products. It is not recommended to expose the circuit to the surface, and the thickness of the fabric is not ideal. At this stage, redirecting creativities is challenging for children aged 0–3 years, for whom safety and comfort are the most important attributes. In this context, the design that serves as an innovation point should be reconsidered.

Idea 2: Development of self-designed fabric

The UK installation art exhibition "Within + Without" inspired the next idea. Installation art has no material limitations, and artists mainly create their own themed artworks through designated spaces. Moreover, visitors enjoy immersive art by entering the artist's space. The researcher designed and developed the play mat as an art piece in an irregular shape with technology support to create a large interactive play environment.

The fabrication method considered the structure of the play mat. The play mat was designed in a sandwich construction. The play mat required 5–6 cm in thickness and softness in the sense of touch. To meet such requirements, the researchers developed and selected the initial prototypes of the top layer after testing with different techniques in the following process. The circuit is fixed in the middle part. The bottom layer is antiskid fabric.

Weaving methodology

The first sample, shown in Figure 5.8, was developed by the electronic frame loom machine model AS4-IPM as a plain-woven fabric sample. The transmittance level of the fabric sample was positive, as shown in the figure below. The creation of the pattern and size of the fabric was limited owing to the natural structure of the machine. Therefore, this fabrication method was not adopted in further work.

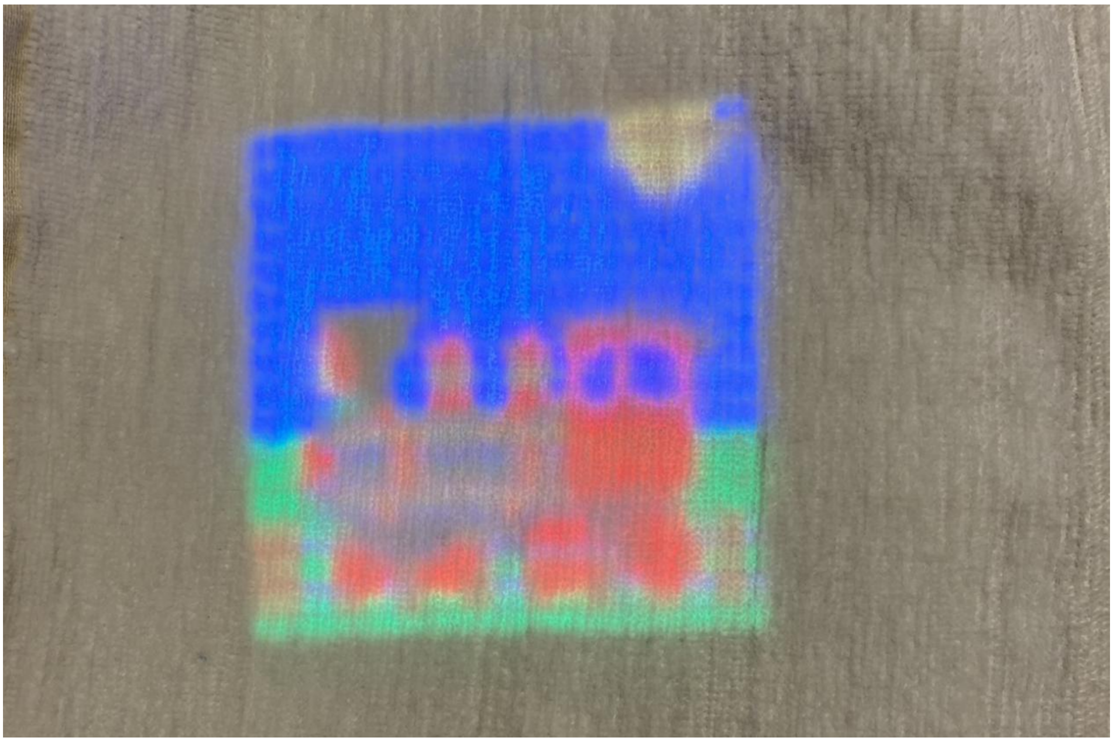


Figure5.8 Fabricated prototype 1

Knitting methodology

The second sample, shown in Figure 5.9, was developed using the WEALMART (WM-01-6766) knitting machine as a plain-woven fabric sample. The transmittance level of the fabric sample was not satisfactory, as it was too thin, and the image appearance was too bright, as shown in the figure. The creation of the pattern and size of the fabric was limited owing to the natural structure of the machine. This fabrication method was not adopted in further work.

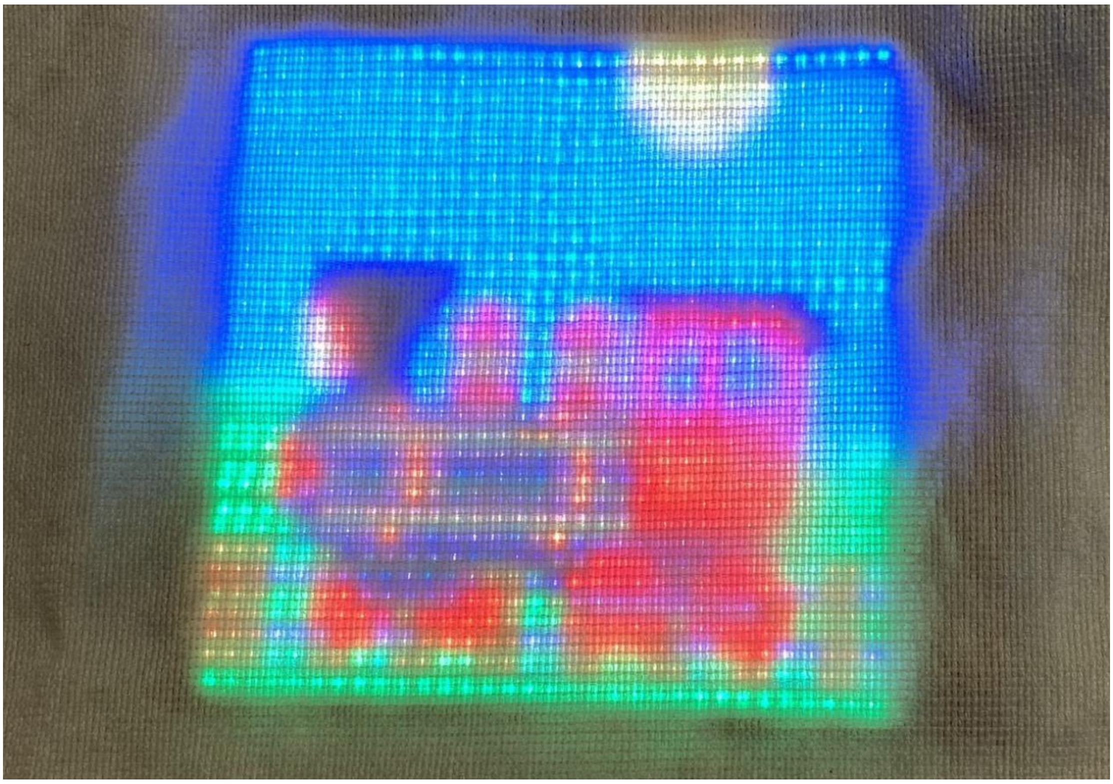


Figure5.9 Fabricated prototype 2

The tufting methodology

The third sample, shown in Figure 5.10, was developed by the tufting method, considering the limitation of pattern creation of the last two failed samples. The figure below shows the small sample developed by the tufting method by using a small frame. The transmittance level of the fabric sample was satisfactory. The creation of the pattern and size of the fabric was also flexible owing to the natural structure of the free-hand technique. Thus, this fabrication method was adopted in further work.

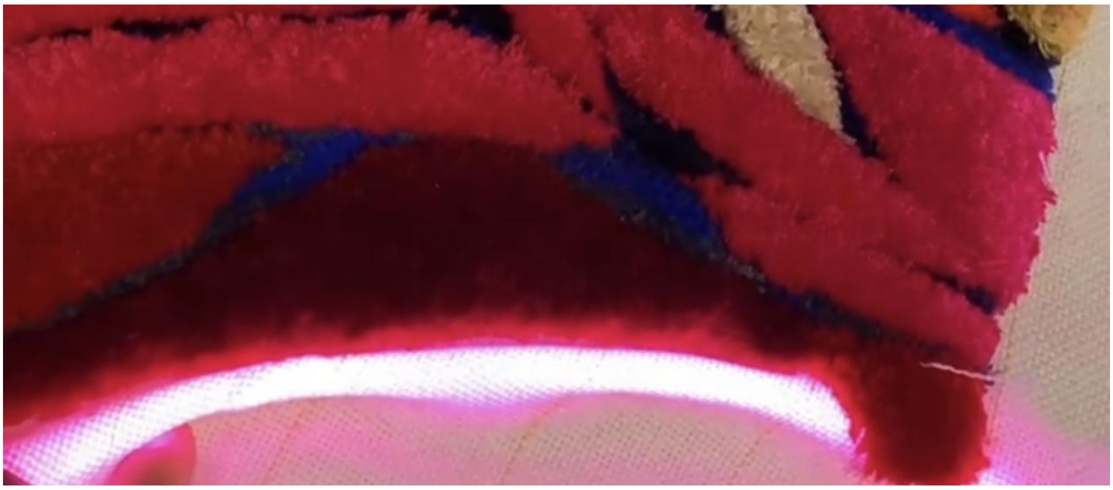


Figure5.10 Fabricated prototype 3

Two types of tufting guns are shown in Figure 5.11. To make a large surface layer for the mat production, one type creates a loose hair effect, and the other creates a thicker effect. The yarn is applied to the designed area of the mat base by feeding it through the gun.

Figure 5.11 The tufting guns used for the interactive play mat

5.2.6 Material selection

The yarn selected for the surface material shown in Figure 5.12 is made of 30% cotton, 70% polyester, and a soft and nontoxic wool called "milk cotton wool." This type of wool is skin-friendly and suitable for the tufting technique and for children's use because the character of the wool induces less hair loss compared to other 100%

polyester wool carpet. The price of the “milk cotton wool” is low, making it conducive to large-scale production, and an extensive variety of colors are suitable for this design concept. The selected material was tested in the previous small sample of fabricated prototype 3.

Figure 5.12 The “milk cotton wool”

5.2.7 Freehand drawing for the design process

Freehand drawing, shown in Figure 5.13, is an indispensable part of product design, and researchers considered designing the most suitable product appearance and function through data collection and customer needs. This theme revolves around the selfless love of mothers for their children, the dependence of children on mothers, and the fact that mothers are the starting point for nurturing life. Researchers associated the theme with a mother's embrace and the anatomical parts that nurture life. The researcher composes the picture by connecting the three closest parts to the child. The researcher created an environment that makes children feel the safest and most comfortable. Such an environment allows children to immerse themselves in learning through play.

Figure 5.13 Freehand drawing for the design process.

The Figure 1-9 puzzle reflects the design ideas inspired by the mother's anatomy and the close connection between the mother and their children. Researchers started sketching from these aspects while considering the engaging environment for toddlers as users. The starting point was sketching different body parts of the mother such. Then, the researchers used their imagination to create playful shapes. The entire carpet combination is irregular and does not restrict the imagination of toddlers in this particular age stage. The interaction can be alone or in group. The play mat set allows toddlers to move around and reassemble each carpet section in this environment. The final play mat has an irregular shape in a few parts; some are 3D, and some vary in height. Figure 5.14 shows the design of the play mat set drawing for final production. The size of the play mat set is around 3.5–5 m^2 and can be adjusted depending on the arrangement of the display method.

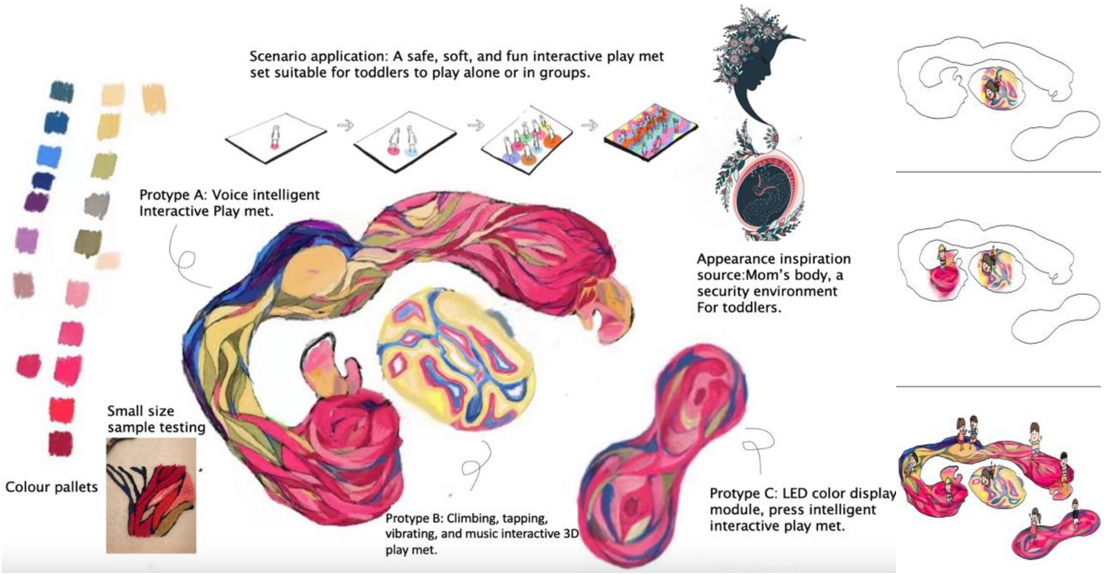


Figure 5.14 Play mat design board for production

5.3 Scenario application diagrams

This combination of play mat sets is divided into A, B, and C, three parts, targeting the particular group of toddlers aged up to 3 years, who have significant differences in abilities. Therefore, three scenario application fields for children at different stages were designed and are shown below. The scenario design considers the story of the interaction between a particular user group and the designed product, and viewers can understand the product's actual use through simple, understandable drawings and text annotations to help viewers better understand user behavior and needs [56].

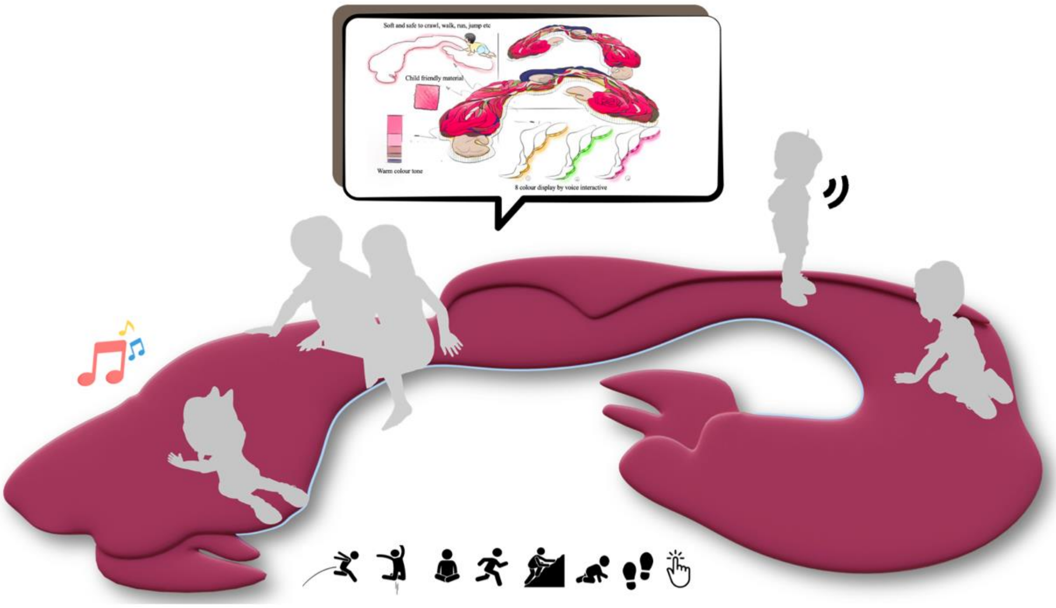


Figure 5.15 Scenario of Prototype A with Voice interactive and photoelectric

The voice interactive photoelectric mat, shown in Figure 5.15, can modify the dialogue and lighting interactive content by modifying the programming code. Users communicate with the voice sensor modular of the mat to activate the lights as part of the interaction process. This project includes preset codes for LED lights with different color instructions. Eight colors are pre-programmed for children to play with: red, yellow, orange, blue, green, pink, purple, and white. Toddlers with better verbal abilities lead the game, while children with weaker speech abilities can interact through imitation. Referring to Chapter 2, the importance of play in early childhood development, such as separate games, team games, observation games, imitation games, big action games, fantasy games, and cooperative games, was considered while designing this play mat. The mat is a big arm measuring around 3.8 m long. Such a large area allows toddlers to run, jump, walk, crawl, and do other activities. Toddlers can thus improve their auditory, visual, language, cognitive, and reactive abilities.

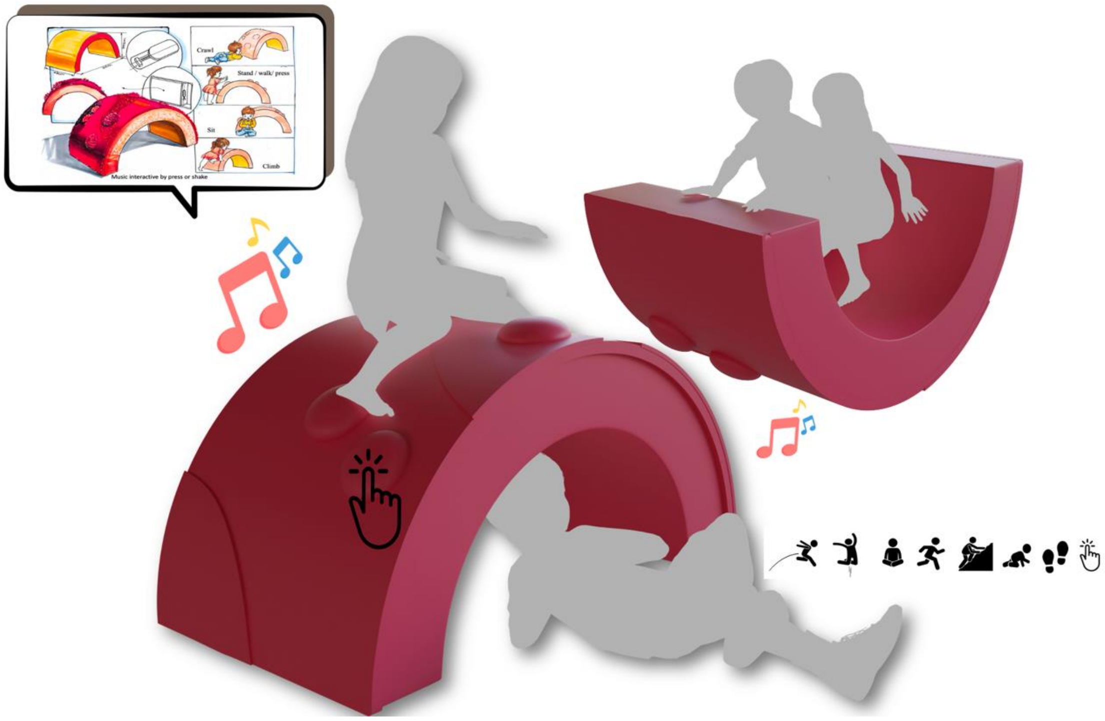


Figure5.16 Scenario of Prototype B Music interaction

The 3D arch bridge within this play mat, shown in Figure 5.16, provides a combination of functions to offer more possibilities for play. First, it emits the musical sounds of different instruments when each ball detail is touched on the surface. Toddlers can also search for different types of music by combining interactive movements such as climbing, jumping, leaning, and sitting. The interior is supported by sturdy sponges, which are soft and safe.

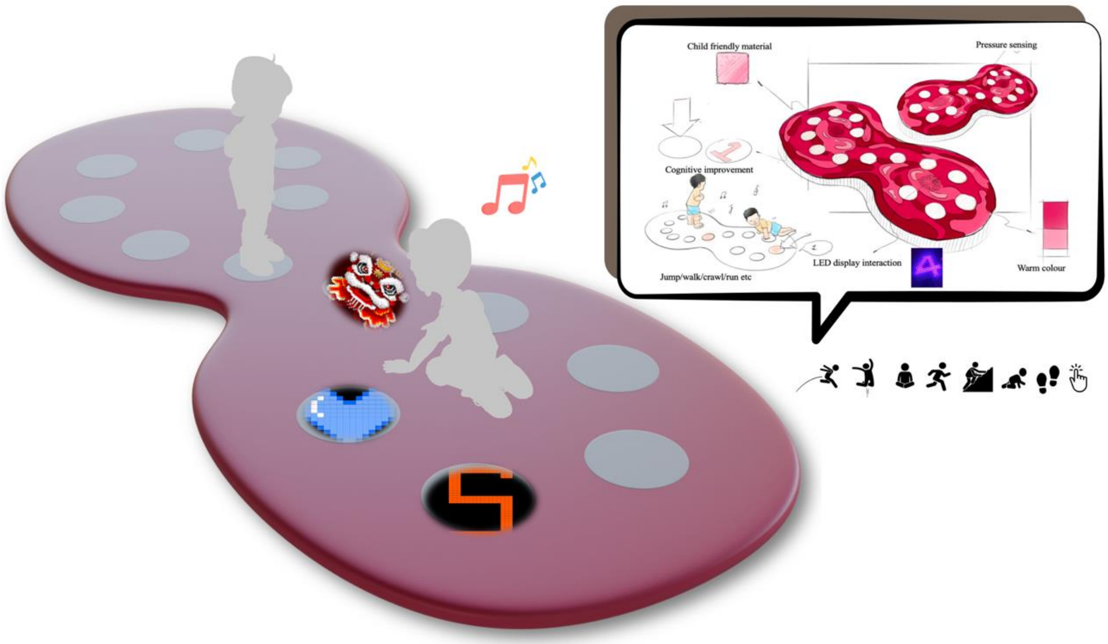


Figure 5.17 Scenario of Prototype C LED display interaction

An animated, full-color display of the play mat is shown in Figure 5.17. Toddlers should be able to walk back and forth on the carpet, which reinforces the idea of free play of the design concept. Toddlers can also explore with their imagination. When a child steps on the white circular area, a different circle displays corresponding animated images, such as graphics, numbers, and colors, to enhance cognitive abilities. In this project, the researcher placed six LED soft screens on the right side and connected them to six pressure sensors on the other side for this project experiment in the stage. Children can engage in different spontaneous, interactive games individually or in groups. All of the interactive methods can be adjusted by programming and coding instruction.

5.4 3D construction view of Prototype A

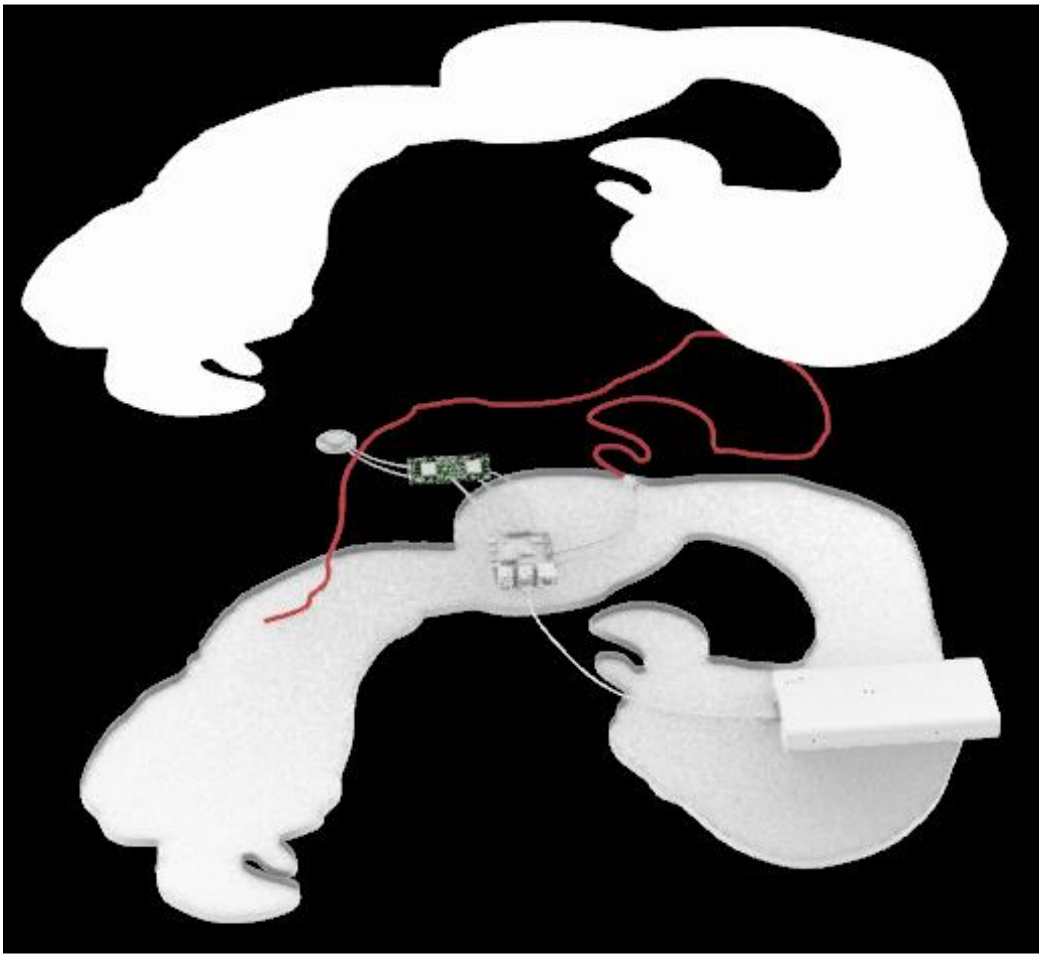


Figure 5.18 The 3D view of prototype A

The 3D construction view shown in Figure 5.18 displays the structure of prototype A, made using 3D max software. This step reduces the number of incorrect samples in product design, saving costs and time, especially for large products such as the play mats in this project. These issues require a 1:1 ratio in size to 3D modeling to confirm the structure before further production of the final product. In the diagram, the tufting carpet is the top layer on the surface, the circuit is in the middle, and the anti-slip fabric is fixed on the bottom.

5.4.1 Explosion structure diagrams

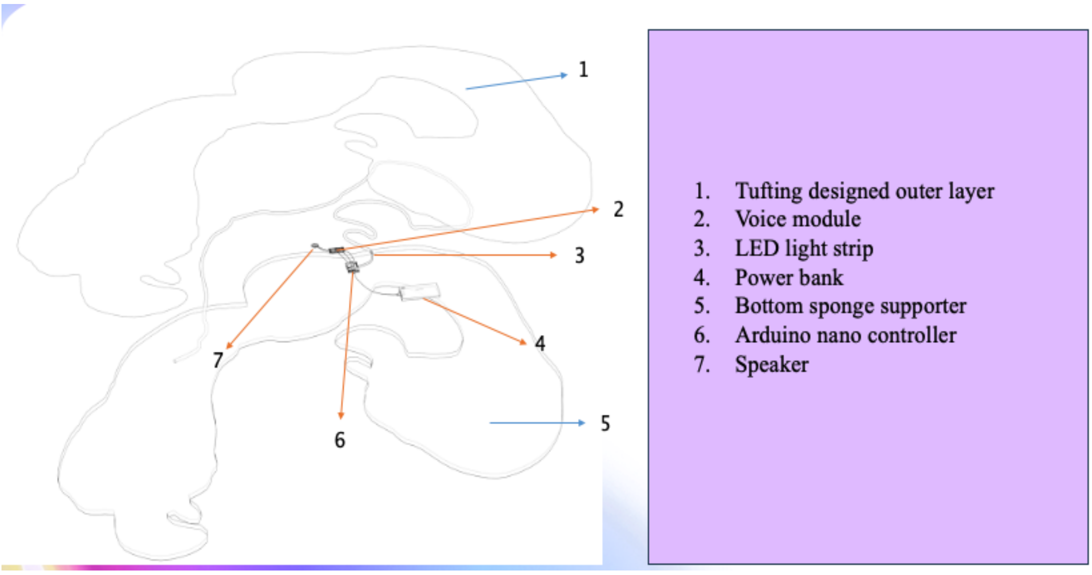


Figure 5.19 The explosive structure diagram of prototype A

The explosive structure shown in Figure 5.19 was made by computer-aided design (CAD) software, which explains the information of each circuit and electronic device and better explains the design structure and the effect after their combination. Each number in the left diagram matches each circuit and electronic device. On the right side of the picture is the electronic component, which includes a voice module, LED light strip, power bank, Arduino nano controller, and speaker.

5.4.2 Circuit Design Idea

The circuit schematics diagram in Figure 5.20 of shows the circuit arrangement layout and final selection of electronic components. The circuit diagram was illustrated using the "FRITZING" software. The circuit arrangement was designed through the design concept of this interaction activity, which depended on the interactive needs of toddlers by the researcher's consideration. The major purpose of prototype A is to practice communication skills, cognitive skills, and significant movement activities during the entire interaction process. This interaction process was thus designed to engage toddlers and the play mat by activating the LED light in the different colors by verbal instructions such as, “Please turn on the red (or other color) light.” However, the instruction and interactive method can be changed by creating another particular coding as instruction. The circuits below include a speaker, LD3320, WS2812B LED strip, and Arduino nano control board. The related function is introduced in Appendix I. The electronic components and their functions are described in sections 5.4.2, 5.5.2, and 5.6.2.

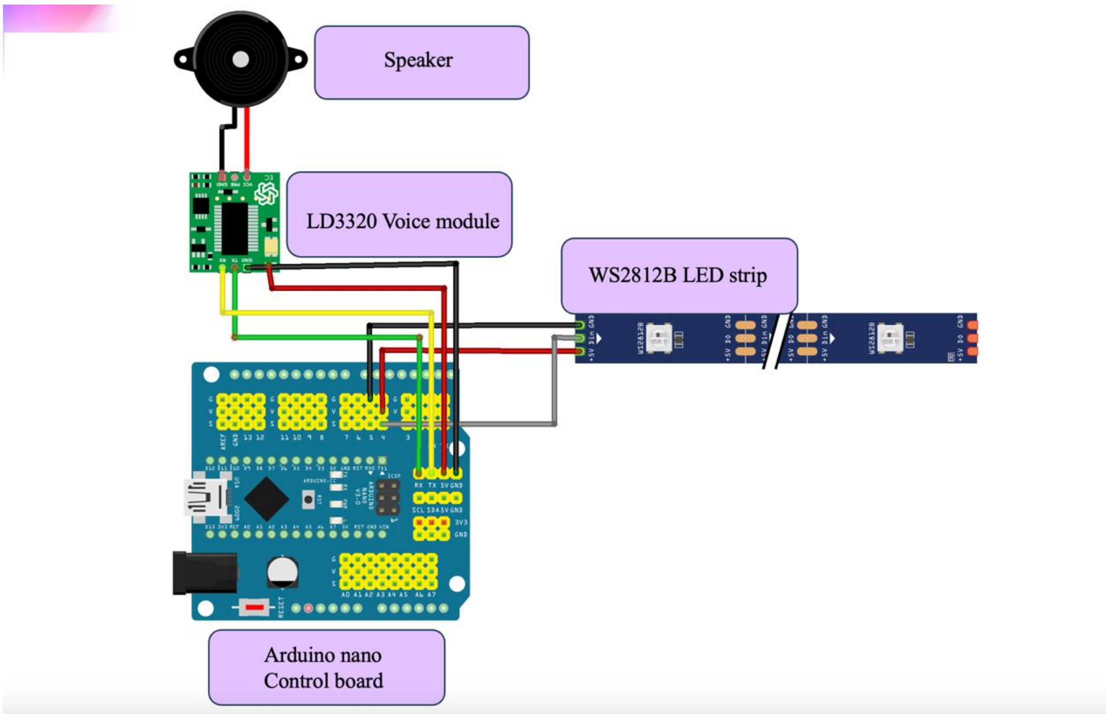


Figure 5.20 Circuit diagram of prototype A

5.4.3 Develop the process of prototype A

Figure 5.21 shows the development process of Prototype A. The selected yarn has finer and softer properties, and four to eight yarns of varying quantities were combined into thicker strands of yarn before production. The play mat base fabric was fixed onto the frame (2 m × 1.8 m) temporarily before production. Based on the large size of the target mat, the researcher enlarged the design image with the projector and separated a large-scale image into a few parts before sketching the outer layer. Then, the researcher joined the back to the entire piece in the final stage. The frame below was customized for this particular project.

Figure 5.21 Development process of Prototype A

The interactive play mat shown in Figure 5.21 is the largest size of the set, with eight images arranged according to the main steps in the development process. Figure 1 shows the customized frame for tufting. The largest size for the workshop is 1.5 m × 2 m, which is not big enough for prototype A. Therefore, the play mat was separated into three parts for development. Figure 2 shows the path of a play activity space conceived by observing the steps length of young children's small footsteps and considering an indoor play area of 5–7 m^2. Figure 3 shows the use of a projector to project the estimated size of the drawn image, Figure 1, onto the production frame. The limitation of the framework is 2 m × 1.5 m. Owing to the size of the workshop space, it was impossible to make it larger, so the production area could only be separated. Before starting the tufting, the researcher divided the carpet structure into three parts: left arm, right arm, and head. According to the layout of the target customer's living room, the angle of the arms can be slightly adjusted at the connection through special parts of the magic tape connection point. Figure 4 shows the test of the color and length of the yarn before sampling. Figure 5 shows that with the assistance of a projector, the researcher could draw the outline by a pencil in the frame. Tufting started from the outer contour, and each color block was pre-marked in words with a pencil. Figure 6 shows slight adjustments during the production process, which arose owing to differences in appearance between the color design and the actual effect, which required the designer's work experience to determine. Figure 7 shows that hair scraping is a highly technical skill in the art of tufting. In addition to the length of the wool, it can also be a gradual layer or multiple layers. In this artwork, there are mainly two lengths: 2 cm and 6 cm. Figure 8 shows the trimmed arm and head, while the other arm needs to repeat the process. Figure 9 shows the installation of the circuit and programming, which is powered by a power bank whose electronic current does not exceed 5 V.

5.5 3D construction view of Prototype B

Figure 5.22 The 3D view of prototype B

The 3D construction view above displays the structure of prototype B, made by 3D max software. This step clearly shows all of the layers of the special arch-shaped parts of the play mat set. These issues required a 1:1 ratio in size for 3D modeling to confirm the structure before further production of the final product. In the diagram, the tufting carpet is the top layer on the surface, the circuit is in the middle of the top, and the second layer is a thick facing fabric stitched on the third anti-slip fabric to support the shape, then fixed with the magic tape on the hard sponge arch bottom parts. There is a flexible opening at the side for fixing the circuit, if needed.

5.5.1 Explosion structure diagrams

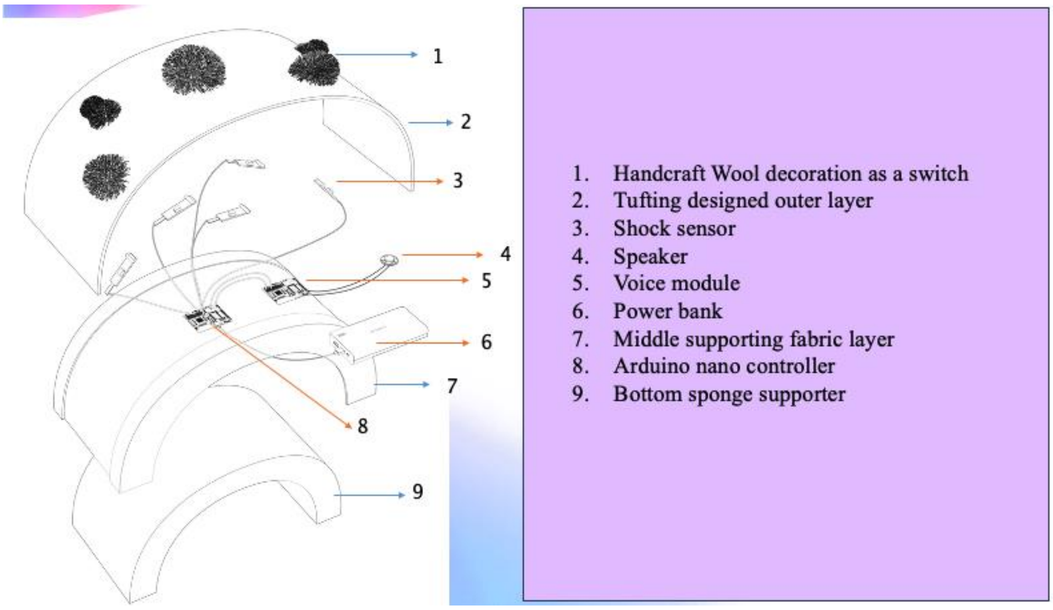


Figure 5.23 The explosive structure diagram of prototype B

The explosive structure diagram is Figure 5.23 was made by CAD software, which explains the information of each circuit and electronic device and better explains the design structure and the effect after their combination. Each number in the left diagram matches each circuit and electronic device on the right.

5.5.2 Circuit Design Idea

As shown in Figure 5.24 shows the circuit layout and final selection of electronic components. The circuit diagram was illustrated using the “FRITZING” software. The circuit arrangement was designed through the design concept of this interaction activity, which depended on the interactive needs of the toddlers by researcher’s consideration.

The major purpose of prototype B is to allow toddlers to practice cognitive skills and significant movement activities during the interaction process. This interaction process was designed to engage toddlers and the play mat by touching or shaking the vibrating sensor under multiple colorful hairballs on the surface of the particular arch mat. Each hairball plays different pieces of instrumental music by pre-coding, which encourages toddlers to search more and activate their multi-movements, like grabbing, crawling, climbing, and drilling. However, the instruction and interactive method could be changed by creating another particular coding as instruction. The circuits below include a vibration sensor, speaker, music player module, and Arduino nano control board. The related function is introduced in Appendix I, and the electronic components and their functions are described in sections 5.4.2, 5.5.2, and 5.6.2.

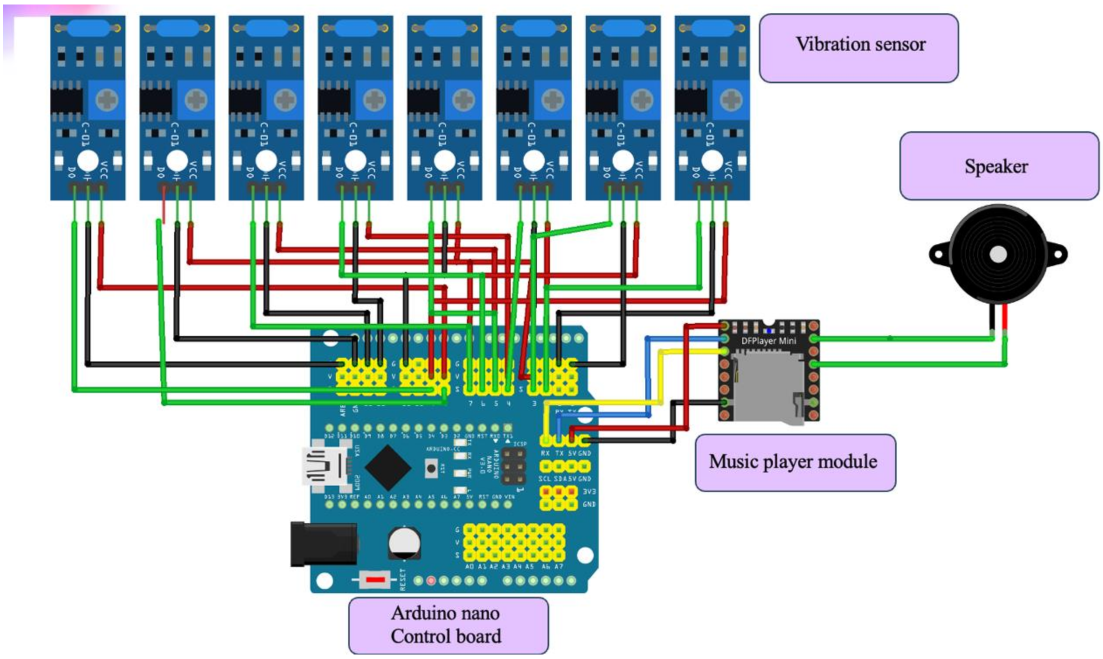


Figure 5.24 Circuit diagram of prototype B

5.5.3 The Development of process of prototype B

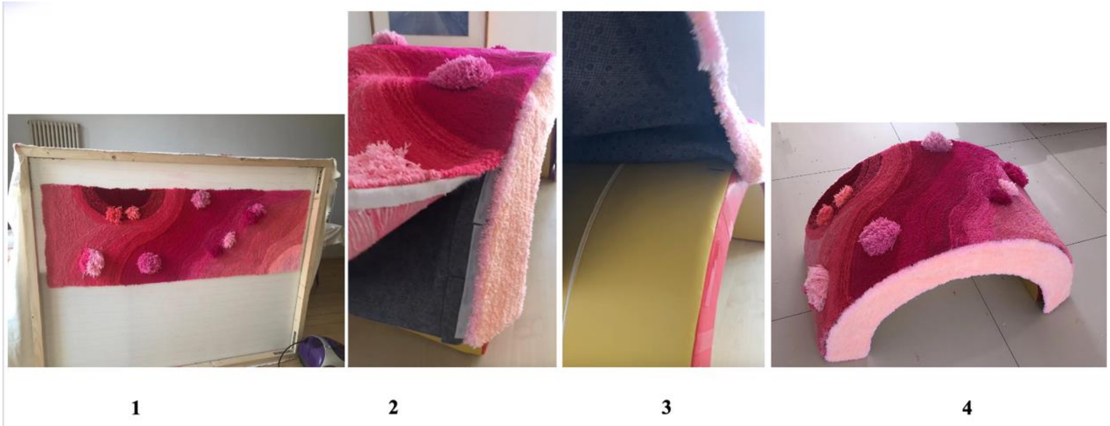


Figure 5.25 Development process of prototype B

Figure 5.25 shows the development process of prototype B. The size of prototype B was designed by researchers with a user-centered approach, observing the most popular climbing height, drilling size, and playing movements of toddlers aged 0–3 years playing in various amusement facilities in the playground. The music interactive play mat was then designed. Figure 1 shows the rectangular size of 1.1 m × 0.5 m, which matches the surface size of the customized supporting sponge base, and the color is the pink gradient color of the warm color system. The hairball on the surface is used as a place for children to grasp when climbing by hand. A vibration sensor is fixed under each hairball, and when children touch the hairball, the vibration sensor triggers the music controller to emit different instrument music. Figure 2 shows the area between the surface and lining layers where the circuit is placed. The side is affixed with Velcro, allowing for maintenance and adjustment of the circuit. Figure 3 shows the junction of the hard sponge with the anti-skid cloth. Figure 4 shows the final look of the prototype. The power bank is a power supply channel, with the electronic current of the circuit not exceeding 5 V.

5.6 3D construction view of prototyping C

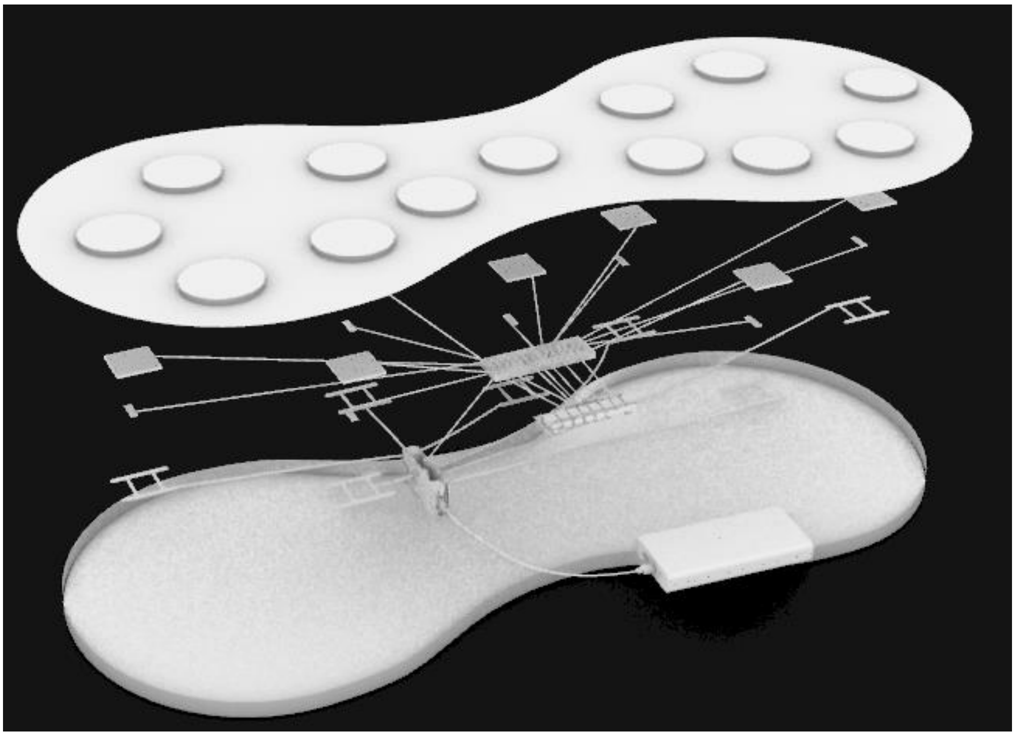


Figure 5.26 The 3D view of prototype C

The 3D construction view displayed in Figure 5.26 is the structure of prototype C, made by 3D max software. This step clearly shows all the layers of this “8”-shaped parts of the play mat set. These issues require a 1:1 ratio in size for 3D modeling to confirm the structure before further production of the final product. In the diagram, the tufting carpet is the top layer on the surface, and the circuit is fixed in the middle of the top and bottom layers with the glue gun and insulating tape. Anti-slip fabric is the bottom layer supporting the shape, and a flexible opening exists on the side for fixing the circuit, if needed.

5.6.1 Explosion structure diagrams

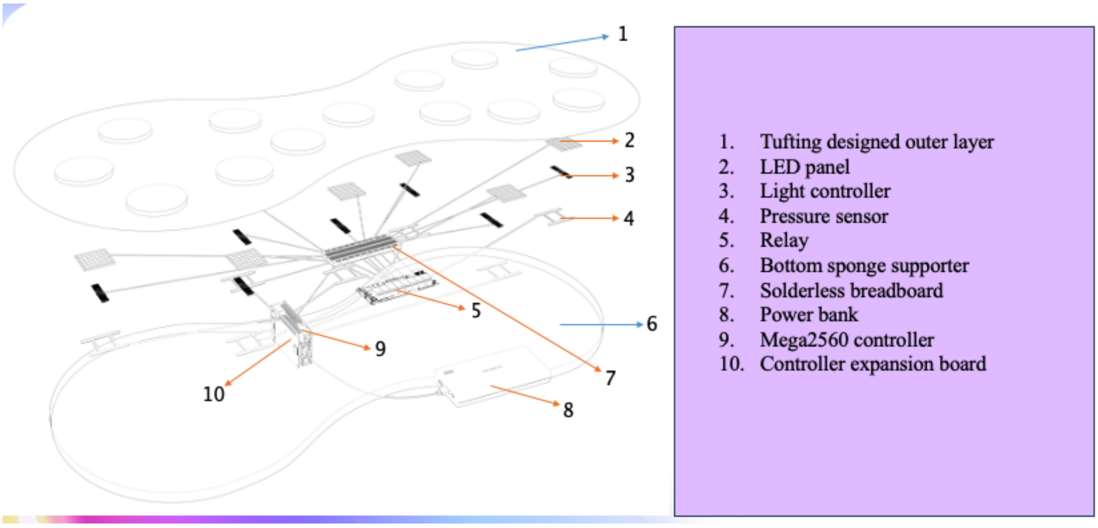


Figure 5.27 The explosive structure diagram of prototype C

The explosive structure diagram shown in Figure 5.27 is made by CAD software, which explains the information of each circuit and electronic device and better explains the design structure and the effect after their combination. Each number in the left diagram matches the circuit and electronic device on the right diagram.

5.6.2 Circuit Design Idea

As shown in Figure 5.28. The circuit arrangement was designed regarding the interactive function required and the final selection of electronic devices after passing the test. It includes a WS2812B LED panel, controller, pressure sensor, electric relay, breadboard, speaker, music player module, and a Mega 2560 main control board. The LED panel is a critical point in this design, with a full-color display, a word display; a thin and soft texture, and low voltage. Therefore, a WS2812B LED panel was chosen for all the required needs. The panel will be filmed with PVC film paper before being fixed to the play mat for better protection. The related function is introduced in Appendix I. The electronic components and their functions are described in sections

5.4.2, 5.5.2, and 5.6.2.

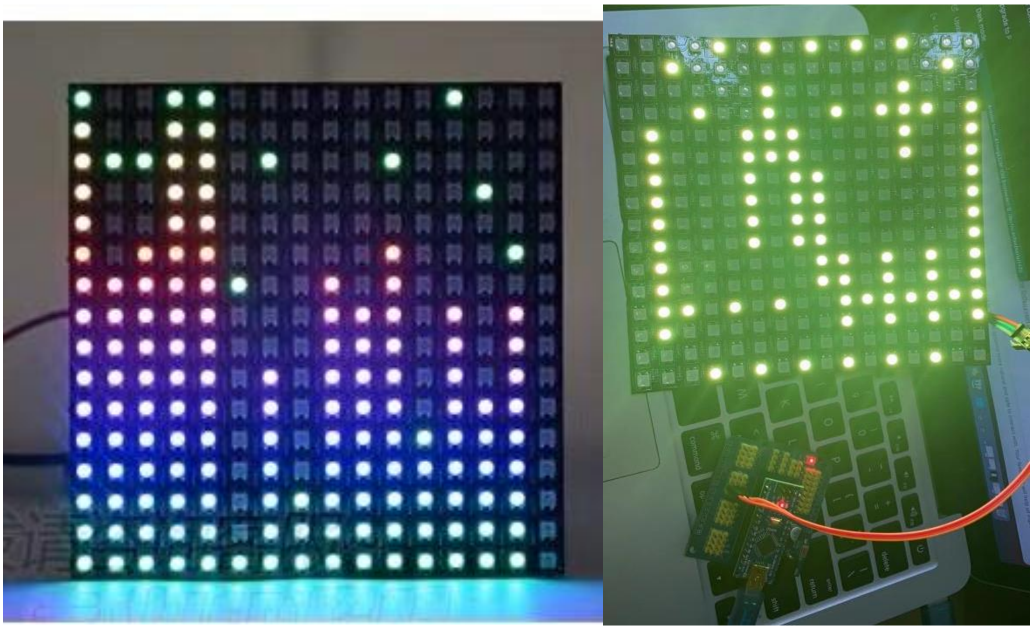


Figure 5.28 WS2812B LED panel

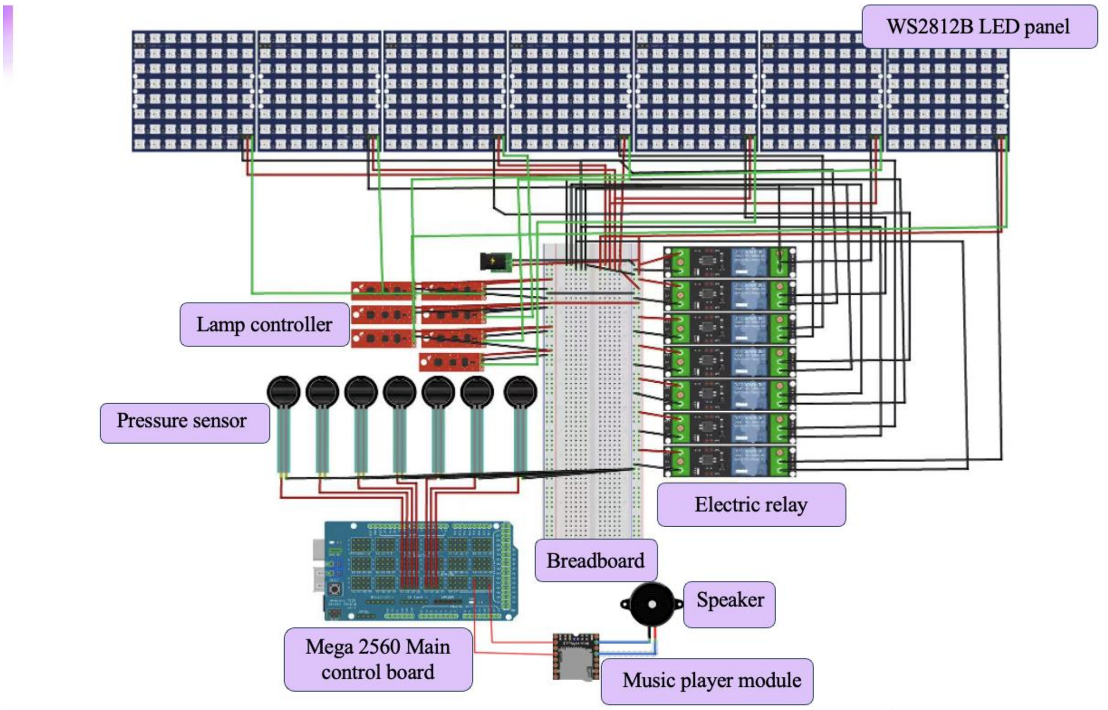


Figure 5.29 The Circuit diagram of prototype C

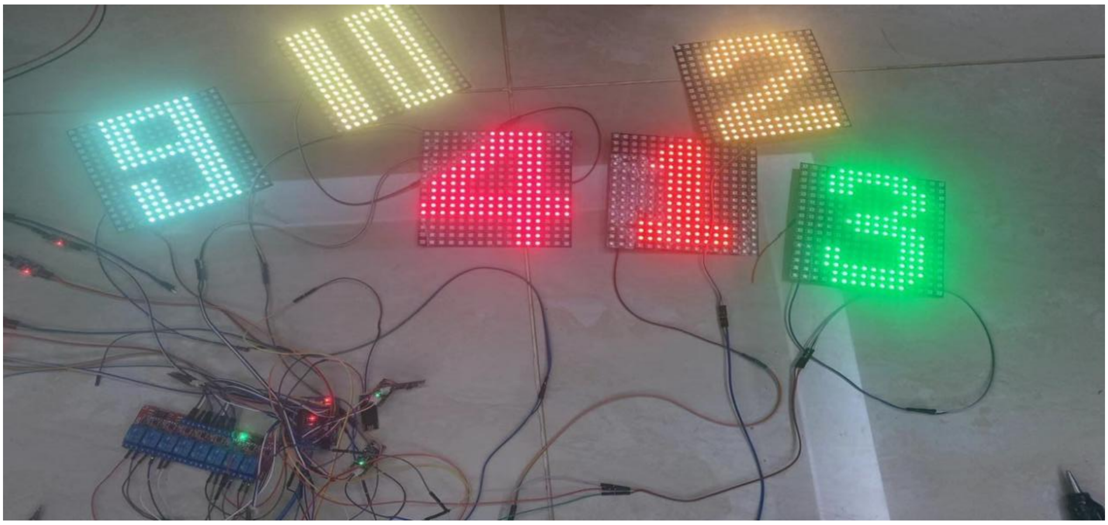


Figure 5.30 The circuit photo of prototype C

Figure 5.30 shows the satisfactory result of the circuit system with coding before fixing it onto the play mat for prototype C.

5.6.3 The development process of Prototype C

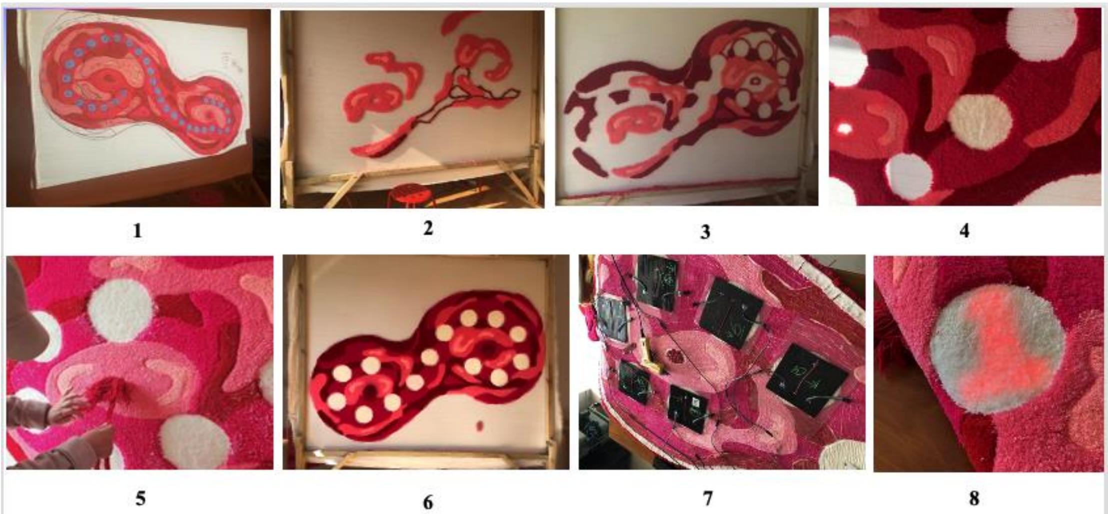


Figure 5.31 Development process of prototype C

This play mat prototype C was designed with the goal of facilitating interaction with toddlers by stepping on, patting, pressing the play mat on these white circles, which triggers LED screens to display numerical patterns through pressure sensors. This interaction aims to improve cognitive and large-movement skills. Figure 1: The size of the carpet is around 2.3 m × 1 m. There are 18 circles on the mat, and the interactive details were designed based on the average size of the feet of toddlers aged 0–3 years. Usually, toddlers' feet sizes in this age group are 8–16 cm long. The white stepping circle is around 18 cm in diameter for this mat, and the spacing between each circle is 10 cm in diameter. According to the inspiration of the number "8" shape, toddlers are encouraged to walk, crawl, jump, run, and take other actions back and forth within this distance. Figure 2 shows the use of a projector to project the designed image. We sketched the pattern with the pencil to annotate the details of the outline. Figure 3 shows the color and trim, leaving the white circular area blank. Figure 4 shows how we placed the LED in a circle for light transmission testing and selected the "white color" through different white yarns and different lengths of yarn. Figure 5 shows the process of hand-plucking balls, which required testing for the most suitable length and size suitable for toddlers' small palms. Figure 6 shows the surface of the finished art carpet being turned, removed, cut out, and fixed to the back lining fabric. Figure 7 shows that the LED panel and sensor were fixed separately, where each sensor controls one LED panel. It can be arranged in groups. In this experimental project, regarding the differences in ability level, cognition, and body movement of toddlers at different ages, the researchers finally fixed six pressure sensors under the six white circles on the left, with the display LED panel under the other six circles. In this experiment, two white circles were left out in the middle point of the mat. This ensured the rank and safety of young children during the kindergarten experiment. Figure 8 shows the digital test when powered on.

Finally, the researcher left a 30-cm-long opening on the edge of the mat and fixed it with Velcro for easy maintenance and adjustment. The power bank supplied the power, and the electronic current did not exceed 5 V.

5.6.4 Animation design

The researcher used commercial pixel art software to design a suitable image size of 16 × 16 cm animation for prototype C, shown in Figure 5.32. This type of animation is saved in lossless compression file formats, such as GIF or PNG. A pixel art generator in the market for online users with a computer screen allows them to automatically upload the image to the system and transfer it to pixel art. Yet, this was not suitable for this project owing the limitation of the LED panel WS2812B and the fact that the arrangement of lights is not as abundant as in computer monitors. However, for a user group of toddlers, choosing this monitor for simple number, pattern, or image display was sufficient, especially with a current of less than 5 V for human safety indicators and soft and flexible features. The below figure shows the animation designs for this project. The researcher designed the black background for all the images, highlighting the image presentation for the benefit of the toddler's concentration, and the black part means lights off, translating to less use of the current intensity.

Figure 5.32 Animation designs

5.7 Programming and coding of Arduino IDE

The basic knowledge of programming and coding of Arduino IDE used for the interactive play mat is given in Appendix II Programming and coding of Arduino IDE 5.7 part 1. The relating coding creation is given in Appendix II Programming and coding of Arduino IDE 5.7 part 2. Below is the instruction order for prototypes A, B, and C.

The instruction of coding for prototype A (Appendix II, part 2)

Instruction order for prototype A: This code uses Adafruit_. The NeoPixel library controls a WS2812B light strip with 150 px. The program receives input through a serial port to change the color of the light strip. In the setup() function, the researcher initialize the serial communication and light strip object. The item variable is initialized to 0. In the loop() function, the researcher first set the brightness of the light strip to 20. Then, the researcher check if there is available data on the serial port. If data are available, the researcher read the serial data and convert it to the integer type, and then the researcher store it in the item variable. Next, the researcher uses the value of the item variable to determine the color to display. Based on the value of the item, the researcher use different colors to light up the light strip. In each iteration of the loop, the researcher set colors pixel by pixel and use rgb_ Display_ 2. Show() updates the light strip display. The coding below reflects the instruction.

The Instruction of coding for prototype B (Appendix II, part 2)

Instruction order for prototype B: This code is an Arduino-based program used to control relays. The following is the parsing of the code: First, an integer array called relay-Pins containing relay pins is defined, with elements A0, A1, A2, A3, A4, A5, and A6. These pins represent the analog input pins on the Arduino board. Using the size of the operator and array index operation to calculate the size of the relay-Pins array, and the researcher divide the result by the size of (relay-Pins [0]) to obtain the value of num-Relays, which represents the number of relays. In the setup() function, configure the relay pin to output mode. By iterating through the relay-Pins array in a loop, the researcher use the pin-Mode() function to set each pin to output mode. In the loop() function, the researcher perform a loop operation to read the value of the analog input port and map it to the state of the relay. After traversing the relay-Pins array through a loop, the researcher use the analog-Read() function to read the value of each analog input pin, and store the result in the analog-Value variable. Using the map() function to map the value of analog-Value in the range 0–1023 to the range LOW to HIGH, and the researcher obtain the Boolean value of relay-State. Finally, the researcher use the digital-Write() function to write the value of relay-State to the corresponding relay pin, thereby controlling the switch state of the relay. The purpose of this code is to read the value of the analog input pin and control the status of the corresponding relay based on the read value. Note that this code assumes that the relay pins have been correctly connected to the Arduino board and that the working voltage of the relay matches the Arduino board. The below coding reflects the instruction.

Instruction for coding for prototype C (Appendix II, part 2)

Instruction order for prototype C: This code uses the NewTone library to control the output tone of digital pins and monitor the input status of other pins. The purpose of the code is to control the output and tone of different pins based on their input states. In the setup() function, the input and output are set modes of the pins, and we set some pins to high-level output. Pins 9–12 and pin 3 are set as input pins, and pin 13 is set as an output pin. The setting also includes initialized communication through a serial port. In the loop() function, the status of each input pin is checked. If the state of a pin is HIGH (i.e., 1), the setting of the corresponding output pin is set to a low level and plays a specific tone on pin 13 through the NewTone library. If the state of a pin is LOW (i.e., 0), then the setting of the corresponding output pin is adjusted to a high level. In addition, the researcher printed the status of pins 9–12 and pin 3 through the serial port for debugging while monitoring the output. The coding below reflects the instruction.

Chapter 6 Evaluation of the interactive play mat

As the user group for this product, toddlers joined the trial experiment for evaluation. This is the innovation part of the design methodology in the project "Design for toddlers with toddlers," and the researcher adjusted the necessary amount after the trial experiment. In this particular age group, some cannot express themselves well, so the opinions of parents, caregivers, or educational institutions of toddlers were essential.

All guardians or parents of the participating children have signed a consent form for participation, which also covers relevant insurance. Additionally, kindergartens provide ample, safe play areas and sufficient teachers to supervise and guide the activities.

Section 6.1 describes how the researchers recorded the play process of the interactive play mat set by the voluntary participation of three groups of toddlers aged 0–3 years of cooperating kindergartens in the trial. Then, researchers recorded the process of the same group of toddlers playing on the commercial play mat. All of the participants obtained the consent of their guardians, and the guardians signed a consent statement before the experiment. The researcher guarantees that all of the data are only for research use. The relevant photos and videos are for research purposes only. Finally, the experiment was completed by comparing the records of data from professional teachers and from the guardian's questionnaire survey. Section 6.2 mainly presents our evaluation of the data of up to 50 children who randomly participated in the interaction activities with the play mat set in the Yixing Public Welfare Science Exhibition in the Yixing Science Museum to obtain the trial experience questionnaire results.

6.1 Comparison trial experiment with toddlers in kindergarten

The experimental mode refers to various similar game comparison studies. After discussions with three kindergarten principals each with 20 years of educational experience, based on factors such as the number of children, age, and gender, three groups of two toddlers each, totaling six participants, were selected to conduct a small number of usage experiments. The commercial play mats, used as the control group, are shown in Figure 6.1. Commercial play mats in the market focus on floor protection purposes, and game function is an additional benefit that generally relies on accompanying adults through spoken delivery of game rules and demonstrations of playing methods and actions while toddlers observe and repeat instructions. The comparison play mats used in the experiments were two play mats provided by cooperating kindergartens, which are similar in size to the interactive play mat developed by the researcher. The experimental comparison samples below show the interactive play mat set produced by the researcher.

Figure 6.1 Commercial play mats 1&2

Figure 6.2 Interactive play mats 1, 2, 3

Experimental rules:

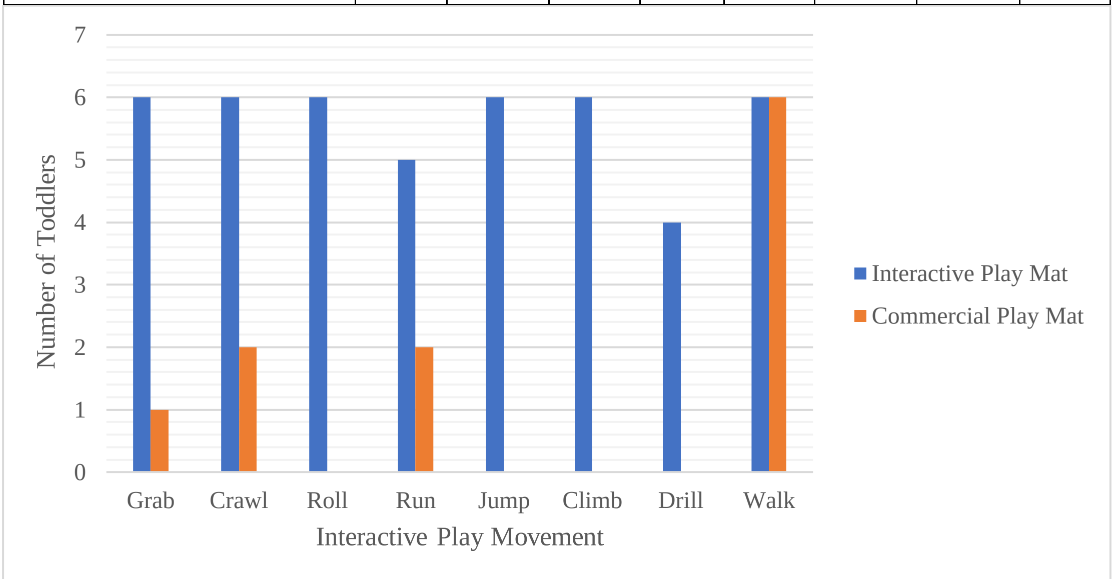
The researcher conducted an experiment between the interactive optoelectronic play mat set trial and commercial play mat. There were two toddlers in a group, one male and one female, for a total of three groups. Moreover, there were 30 min per group (can be added or subtracted appropriately) for each play mat. Four adult hosts were present, and an adult accompanied each child to observe and play one on one, taking photos and recording while ensuring the safety of the children. During this period, one main host-maintained order, while another monitored the technical aspects of video recording and the regular operation of related electrical appliances. The video recorder was positioned in the room in advance. The children had not seen the interactive environment tested or contributed to the development of these technologies. This game test mainly observed children's reactions and playing time during autonomous play on interactive and commercial play mats. On the questionnaire record form, there were clear action names, play items, duration, satisfaction ratings, supporting comments for each research direction observed. Finally, statistics were collected, and the data were organized using an Excel spreadsheet. The discussion is detailed in the conclusion in section 6.3. The questionnaire samples and experiment videos are attached in the Appendix. For all of the questionnaires, the design and development concept is an attractive, interactive play mat that serves as a motivational tool for self-directed activities by targeting eight significant movements beneficial to toddlers' physical and mental health development. A total of six children in three groups joined the experiment with the interactive photoelectric play mat set and the commercial play mat.

Questionnaire 1 (Action test)

This questionnaire mainly focused on observing the toddlers' free play activity behavior. The y-axis in Figure # represents the number of people, and the x-axis displays the names of the movements, including grasping, climbing, rolling, running, jumping, drilling, and walking. Moreover, blue represents the interactive photoelectric play mat set, and orange represents the commercial play mat in the chat. The questionnaire survey statistical table clearly shows that almost all of the marked actions required appeared on the interactive photoelectric play mat set, including grasping (6), climbing (6), rolling (6), running (5), jumping (6), climbing (6), drilling (4), and walking (6). Some unlisted movements appeared in the video record. However, the commercial play mat was recorded with less action, including grasping (1), climbing (2), rolling (0), running (2), jumping (0), climbing (0), drilling (0), and walking (6). The results indicate that the interactive photoelectric play mat set has significant advantages. The following table and chart show the relevant data.

Table 6.1 The data collection of toddler's significant movements

	Grab	Crawl	Roll	Run	Jump	Climb	Drill	Walk
Interactive Play Mat	6	6	6	5	6	6	4	6
Commercial Play Mat	1	2	0	2	0	0	0	6



Chat 6.1 The data collection of toddler's significant movements

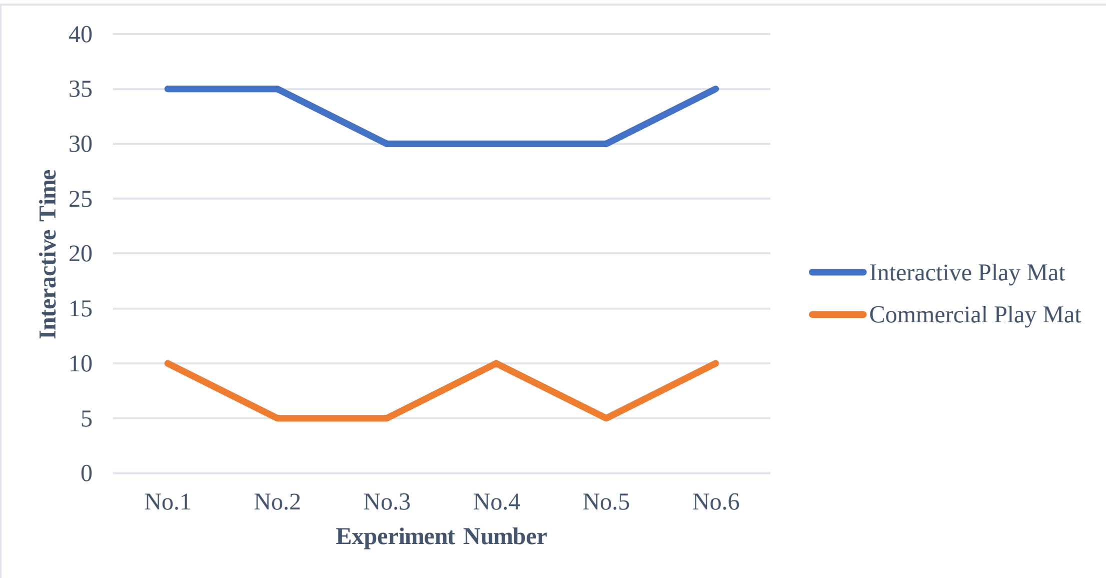
Questionnaire 2 (Duration time test)

This questionnaire mainly focused on observing the time spent on the toddlers' free-play activity behavior. The results compare the effect between the interactive play mat and the commercial play mat. The y-axis number represents the time spent, and the x-axis displays the toddlers' names as No. 1, No. 2, No. 3, No. 4, No. 5, and No. 6 for privacy. Blue represents activities with the interactive photoelectric play mats set, and orange represents activities with the commercial play met. In detail, No. 1 spent 35 min on the interactive photoelectric play mat set and 10 min on the commercial play mat;

No. 2, 35 min on the interactive photoelectric play mat and 5 min on the commercial play mat; No. 3, 30 min on the interactive photoelectric play mat and 5 min on the commercial play mat; No. 4, 30 min on the interactive photoelectric play mat and 10 min on the commercial play mat; No.5, 30 min on the interactive photoelectric play mat and 5 min on the commercial play mat; and No. 6, 35 min on the interactive photoelectric play mat set and 10 min on the commercial space completed. The results indicate that the interactive photoelectric play mat set has significant advantages. The following table and chart show the relevant data.

Table 6.2 Duration time (mins)

	No.1	No.2	No.3	No.4	No.5	No.6
Interactive Play Mat	35mins	35mins	30mins	30mins	30mins	35mins
Commercial Play Mat	10mins	5mins	5mins	10mins	5mins	10mins



Chat 6.2 Table 6.2 Duration time (mins)

Questionnaire 3 (Experience satisfaction index)

This questionnaire mainly focused on observing the experience satisfaction index of toddlers' interactive play movement and behaviors during the activities. This questionnaire defined how interesting the product was considering the participant's reaction. The observer gave a score of 0–10 depending on the reaction of toddlers while making the significant movement list shown on the x-axis. 0 means less exciting or not exhibiting the relating movement, and 10 means very interesting or strongly exhibiting the related movement. The y-axis listed the experience satisfaction index of 0–10. The blue table represents the activities with the interactive photoelectric play mat, and the mean value between all of the children, with all movements, was 9–10.

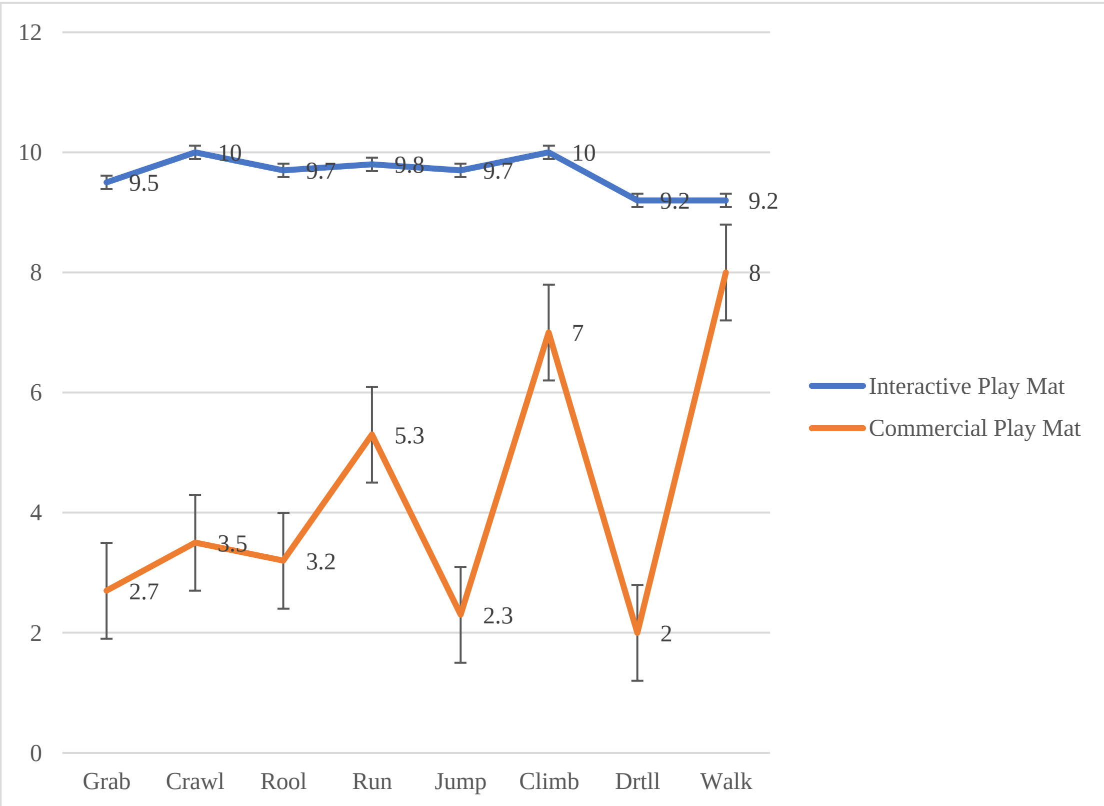
Moreover, the orange table represents the activities commercial play mat; the mean value was low compared to the result of the activities with the interactive photoelectric play mat set. The mean value of the experience satisfaction index of the interactive play mat set was much higher than that the commercial play mat; it reflects the toddler's interest, and the demonstration of the related movement on the interactive play mat was dramatically higher than that on the commercial play mat. The following table and chart show the relevant data.

Table6.3 Experience satisfaction index of interactive play mat

	Grab	**Crawl**	**Roll**	**Run**	**Jump**	**Climb**	**Drill**	**Walk**
No.1	10	10	10	10	8	10	8	10
No.2	10	10	10	10	10	10	10	10
No.3	8	10	10	10	10	10	9	8
No.4	10	10	10	10	10	10	10	8
No.5	9	10	9	9	10	10	8	9
No.6	10	10	9	10	10	10	10	10
Mean	9.5	10	9.7	9.8	9.7	10.0	9.2	9.2
Stdev	0.83	0	0.51	0.40	0.81	0	0.98	0.98
CV	0.08	0	0.05	0.04	0.08	0	0.10	0.10

Table 6.4 Experience satisfaction index of commercial play mat

	Grab	Crawl	Roll	Run	Jump	Climb	Drill	Walk
No.1	2	4	4	6	2	0	0	8
No.2	4	6	2	6	2	2	2	10
No.3	2	6	3	8	2	0	2	8
No.4	0	2	4	6	4	2	2	6
No.5	6	2	4	4	2	0	4	6
No.6	2	1	2	2	2	0	2	10
Mean	2.7	3.5	3.2	5.3	2.3	0.7	2.0	8.0
Stev	2.06559	2.168	0.983	2.066	0.816	1.033	1.265	1.789
CV	0.7746	0.619	0.31	0.387	0.35	1.549	0.632	0.224



Chat 6.3 The experience satisfaction index during the activities

Overall, the feedback from the cooperating kindergartens was positive. The kindergarten principal filled out a product experience questionnaire designed for buyers with 20 years of professional management experience. In the questionnaire, the principal stated that she was willing to purchase meaningful children's products for the kindergarten by observing the product's function and quality. She believed that this product creates a strong interest in children and encourages their active participation in play. She requires significant assistance in early childhood education work. She believes this product has more purchasing value than currently used products and offers excellent benefits for the growth of children in their early childhood development. The related feedback on questionnaire forms is attached in the Appendix.

Photos of the trial experiments in cooperation kindergarten

Figure 6.3

Figure 6.4

Figure 6.5

Figure 6.6

Figure 6.7

Figure 6.8

Figure 6.9

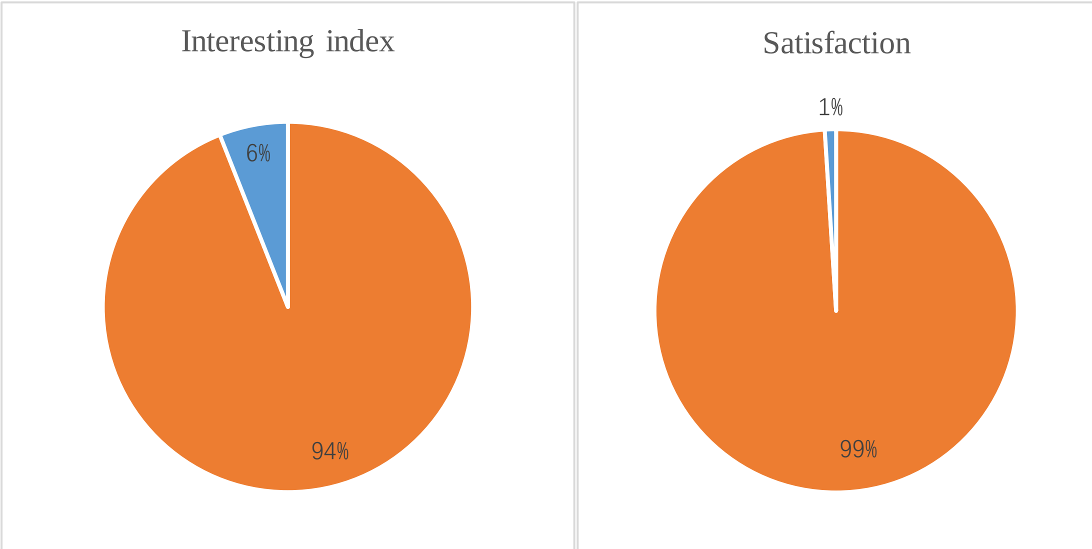
Figure 6.10

6.2 Public welfare science exhibition and feedback

The 3^{5th} Yixing Public Welfare Science Exhibition invited the team behind the interactive photoelectric play mats set to participate in the exhibition. The researcher planned the interactive activities with volunteer audiences for further feedback, mainly evaluating the satisfactory data by up to 50 children who had randomly participated in the interaction activities. The interaction duration for each volunteer audience with an interactive photoelectronic play mat set was 5–10 min. Volunteers aged under 12 years filled out the satisfaction questionnaire by guardians, while those aged over 12 years completed them independently. A total of 50 questionnaires were used for the evaluation results of the experiment shown in the table and reflected in the chats below.

Table 6.5 Interesting index and satisfaction data

	Interesting index	Satisfaction
Agree	94%	99%
Disagree	6%	1%



Chat 6.4 The Interesting index and satisfaction data

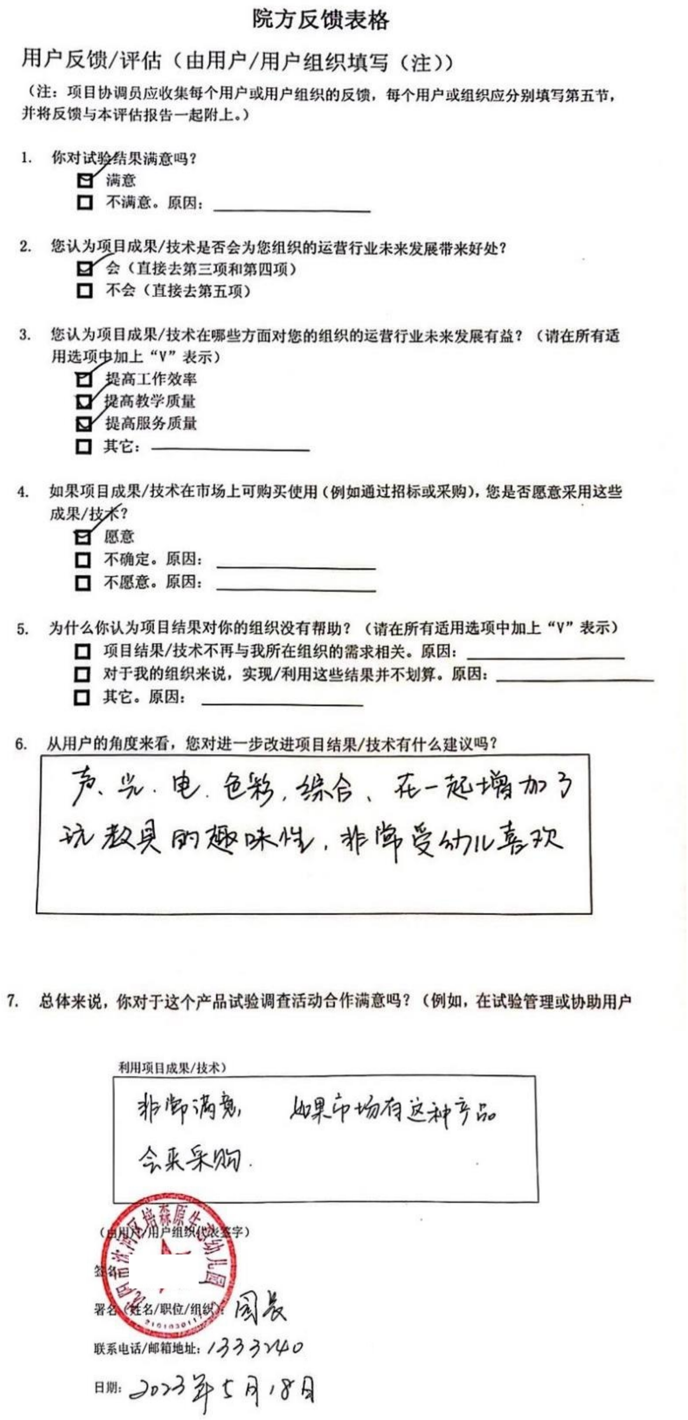
Photos of the interaction activities in the exhibition

Figure 6.11

Figure 6.12

6.3 Feedback from the principal of the cooperating kindergarten

Figure 6.13 shows a feedback form filled out by the principal of the experimental kindergarten. She and the teachers participating in the experiment expressed their recognition of this product. They felt that it significantly affected the development of children's cognition and physical activity. Children showed strong interest and spontaneously participated in various interactions, garnering recognition from the professional perspective of the principal and teachers. Thus, they expressed being willing to purchase such products.



院方反馈表格

用户反馈/评估（由用户/用户组织填写（注））

（注：项目协调员应收集每个用户或用户组织的反馈，每个用户或组织应分别填写第五节，并将反馈与本评估报告一起附上。）

1. 你对试验结果满意吗？
   - ☑ 满意
   - ☐ 不满意。原因：________

2. 您认为项目成果/技术是否会为您组织的运营行业未来发展带来好处？
   - ☑ 会（直接去第三项和第四项）
   - ☐ 不会（直接去第五项）

3. 您认为项目成果/技术在哪些方面对您的组织的运营行业未来发展有益？（请在所有适用选项中加上"V"表示）
   - ☑ 提高工作效率
   - ☑ 提高教学质量
   - ☑ 提高服务质量
   - ☐ 其它：________

4. 如果项目成果/技术在市场上可购买使用（例如通过招标或采购），您是否愿意采用这些成果/技术？
   - ☑ 愿意
   - ☐ 不确定。原因：________
   - ☐ 不愿意。原因：________

5. 为什么你认为项目结果对你的组织没有帮助？（请在所有适用选项中加上"V"表示）
   - ☐ 项目结果/技术不再与我所在组织的需求相关。原因：________
   - ☐ 对于我的组织来说，实现/利用这些结果并不划算。原因：________
   - ☐ 其它。原因：________

6. 从用户的角度来看，您对进一步改进项目结果/技术有什么建议吗？

   声、光、电、色彩、综合、在一起增加了玩教具的趣味性，非常受幼儿喜欢

7. 总体来说，你对于这个产品试验调查活动合作满意吗？（例如，在试验管理或协助用户利用项目成果/技术）

   非常满意，如果市场有这种产品会来采购。

（由用户/用户组织代表签字）

签名：

署名（姓名/职位/组织）：园长

联系电话/邮箱地址：1333240

日期：2023年5月18日

Figure 6.13 Feedback form

6.4 Concluding remarks

The researcher though researched, designed, and developed a play mat for safe play testing activities through photoelectric interaction, aiming at the user group of toddlers aged 0–3 years. The difference between the actual behavior of toddlers during the most beneficial period of physical and mental development was examined through gameplay and a comparison of commercial play carpets in the experimental group. In this experiment, the advantages of the photoelectric interactive play carpet designed and developed by the researchers were evaluated based on the children’s game attitude, facial expressions, body movements, playtime, and relationship development, with peers or alone. The experimental results confirm the expected positive results.

Chapter 7 Conclusions

This chapter summarizes the important findings of the study, describes the limitations, and discusses future work directions.

7.1 Summary and Conclusions

Recent research has identified the technical barriers to interactive textiles, including electronic yarns, in the current market. Many products fail to reflect the ideal combination of textiles and technology. Therefore, this study has been focused on research direction: interactive electronic textiles and their applications. First, the development of innovative electronic yarns produced a series of electronic yarn products that are smaller, more waterproof, softer, more durable, and more aesthetically pleasing than existing commercial electronic yarns. The results of the experimental data comparison indicate that the developed electronic yarn overcomes the limitations of existing electronic yarns on the market. Then, by using electronic yarn to produce beautiful and fashionable shoe uppers, the product results are displayed. The study considers the structure of the yarn itself, including the selection and application of materials for each part, from microelectronic components and yarn cores to the combination between load-bearing yarns, winding yarns, and finally, waterproofing and weaving. By utilizing the characteristics of repeated experiments in Action research methodology, the spinning effect of different materials was tested, and the yarn achieved better performance than expected. This yarn was compared with commercial electronic yarn through experimental data, and the results showed that it is waterproof, soft, durable, comfortable, and low-cost.

Secondly, the design and production projects of interactive textiles suitable for children under 3 years old are derived from the research on electronic yarn. A user-centered design method has been developed, which utilized the interactive functions of sensing and reality electronic devices in soft textiles to create interactive play blankets. The interactive play carpet was a series inspired by electronic yarn design. A user-centered design method that integrates practical base research methodology with young children under the age of 3 in their prime period of brain development, in order to seize the major action activities required by toddlers during this period, accompanied by cognitive, gaming, and other fun interactions to enhance physical and mental development opportunities. Taking toddles as the first consideration, designing interactive play mat includes surface textile structure design, color and pattern design, selection and production of textile raw materials, product structure design, electronic component selection, circuit layout structure design, integrated system, sensor selection, and including full-color modular fabric display, Arduino program and programming control system, safety regulations for children's products, User product trial testing method, testing the final optimized product. Toddlers spontaneously interacted with products through auditory, visual, tactile, and other related perceptual abilities, creating an interactive scene environment. The research has achieved its objectives. 1. It revealed the latest technologies and applications of interactive electronic products and components through existing products and literature. 2. It identified existing problems and innovation potential, as well as the strength of competitors. 3. It adopted the user positioning to carry out design through a user-centered design concept. 4. Preliminary samples have been designed and tested. 5. Modifications were made by evaluating the initial sample through experiments. 6. Toddlers participated in trial testing and experimental evaluation as users. 7. Final production optimization of high-quality finished products.

The two research projects' design process and product contribute to the direction of interactive textile design that has not appeared in previous literature.

7.2 Contributions

This research adopted the action research methodology in the electronic yarn development project and practice-based research methodology in the interactive play mat development project. The two projects combined artistic and technical knowledge to create high-value interactive textiles to make valuable contributions to the textile design industry in theory and practice, design, education, and application of interactive textiles.

7.2.1 Contributions to theoretical research

The electronic theoretical design flow model yarn and interactive play mat were derived and based on the concept of "user-centered design methodology" in industrial design, fashion, and textile design. In electronic yarn development, the project used the action research methodology, including the 'problem formulation,' 'building, invention, and evaluation,' 'reflection and learning,' and 'formalization and learning.' In interactive play mat development, the project used practical-based research methodology, including 'design inspiration,' 'analysis stage,' 'design of the initial prototype stage,' ‘details design finalized,’ and ‘reflection.’ This study investigated users’ needs, scenarios, and objectives; identified, analyzed, and solved problems through design; and finally evaluated the unique innovation of the designed and produced products and user feedback. In the past, there have been few cases in the design field where users compared, evaluated, and modified the initial and commercial samples of interactive textiles. Generally, they only estimated the demand, and not many records of children's interactive products were tried and modified before the final sample was completed. Moreover, only a few interactive textile products are available for toddlers aged under 3 years, and none aimed for significant body movement. This practical approach significantly increases current knowledge and is unique, thus serving as a reference for researchers or designers in other design fields.

7.2.2 Contributions to practical research

The electronic yarn project was a design and development project aimed at achieving a depth of 1 mm, softness, waterproof ability, long duration, and integration with micro-electronic components. The interactive luminous electronic yarn series was completed by understanding relevant technical knowledge and it was combined with the fashion aesthetics trend of selecting wrapping yarns to complete the collection of fashionable electronic yarn. We also developed a pair of fashionable glow-in-the-dark shoe uppers made of such electronic yarn.

The interactive play mat project was designed and developed in an irregular-shaped play mat for toddlers aged under 3 years. The related technology and application were for immersive interactive textiles, including a full-color modular fabric display, audio communication, a fabric keyboard, a wireless communication unit, product structure design, electronic component selection, circuit layout structure design, an integrated system, sensor selection, Arduino program, and a programming control system. We developed interactive play mat prototypes A, B, and C, each with different interaction approaches and functions. The prototypes can be used alone or in combination with other products.

7.3 Limitations of this study

This study had some limitations, as follows:

1) The length of the developed electronic yarn limited the first project, although modifications can be made to the pattern design and textile structure to compensate for this deficiency. However, if this project involves manufacturing large patterns, the resistance aspect for bigger sizes may also be a technical limitation to a wearable interactive textile;
2) Interactive plat mat prototype A only allowed for setting a single language of the voice module at a time. The researchers are still searching for a solution to add a multi-language recognition system. Second, the circuit system in the middle layer is covered by the play mat's outer layer, and the surface layer is not waterproof. The current research phase has not yet started production research on the play mat's waterproof ability;
3) Interactive play mat prototype B cannot be washed. This direction has

not been investigated yet and is essential given the target users. A hygienic environment is a necessary consideration step in development for such users;

4) Interactive play mat prototype C is limited in the duration of the pressure sensor. The outer play mat surface covers the commercial pressure sensor components. However, according to the user's age and the game method, one of the sensors lost control after the trial experiment. Second, the same outcome was observed with the full-color modular fabric displays. However, it cannot be washed, and the textile surface layer is not waterproof.

7.4 Implications for future research

The implications of our study for further research in the field are as follows:

1) Investigate the application of water resistance to enhance practicality in daily life. For the user group of toddlers under 3 years old, maintaining a hygienic environment is a crucial consideration for development; it can be applied in their daily lives as part of their environment.
2) Study and enhance the layout of the circuit and the storage area for the interactive play mat prototypes.
3) Design and develop a longer duration 'full-color fabric display module for interactive play mat prototype C. The commercial soft LED display screen used for the interactive play mat is fragile;

4) Explore new interactive gaming ideas for toddlers' early-age development;
5) Design a specific lockable side trim as a fixture entrance for machinery maintenance in interactive textile products or for the development of future interactive products.

In this design theme, the developed immersive interactive textiles benefit the user group of toddlers aged under 3 years. However, the design and application possibility of our developed products can be extended to other applications in the future. The cooperative trial experiment in kindergarten received multiple positive reviews from the hospital, parents, and users (toddlers), with the former two groups expressing a desire to purchase the product.

APPENDICES

Appendix I The electronic components and their functions refer to chapter 5.4.2/ 5.5.2/5.6.2

This chapter records the main electronic components used and their functions supported the interactive play mat project for toddlers. Refer to chapter 5.4.2/ 5.5.2/5.6.2.

ESP8266

ESP8266 Low-cost Wi-Fi module that is a complete Wi-Fi network solution that integrates TCP/IP protocol stack and can communicate with MCU through the serial port. It can also run as an independent MCU. ESP8266 was designed by Lexin Company in China, and its prototype is the Espress if ESP8266EX chip. The ESP8266 module includes a central control chip and some peripheral circuits, including Wi-Fi antennas, crystal oscillators, and peripheral interfaces. ESP8266 can communicate with other devices, including sensors, actuators, LCD screens, etc., through its GPIO pins.

Buzzer

A buzzer is an electronic audio device that can generate simple sounds or beeps. It usually consists of a diaphragm, a vibration device, and a driving circuit. Sound effect: The buzzer can produce sounds of different frequencies and tones, such as continuous sound, pulse sound, or alarm sound. It can be used for reminders, alarms, indications, or to convey simple information. Application field: Buzzers are widely used in various electronic devices and systems.

Arduino nano

Arduino Nano is a compact and easy-to-use open-source electronic prototype platform based on the Atmel AVR microcontroller, there are 14 digital input / output pins and 8 analog input pins. Its volume is minimal, only 18 x 45 mm, making it very suitable for projects with limited space. Arduino Nano can be connected to a computer through a USB interface for writing, uploading, and running code. It supports C/C++language programming and has an easy-to-use Arduino IDE development environment, allowing users to use it quickly. Arduino Nano has multiple application scenarios, such as robot control, smart home, electronic games, automation control systems, etc.

Vibration sensor

Vibration sensors are devices that can detect and measure the vibration or vibration of objects. It can convert mechanical vibration or vibration signals of objects into electrical signals, thereby achieving vibration perception and monitoring. Vibration sensors typically consist of mass blocks, springs, and sensitive components.

Music playback module

The MP3 playback module is a device that integrates an MP3 decoder and audio output circuit, used to play audio files stored in an SD card or flash memory chip. It can decode digital audio data into analog signals and output high-quality music or speech through speakers or headphones.

Speech recognition module

A speech recognition module integrates voice signal processing and Natural language processing technology, which converts human voice into recognizable and understandable text or commands. It analyzes and decodes sound features, intonation, speech speed, and other information in speech signals, converting them into computer-processed text form. The speech recognition module usually consists of a microphone, signal processing chips, speech recognition algorithms, and interfaces. It can receive human input and convert speech into text results through audio signal preprocessing, feature extraction, and model matching. These text results can be further processed and understood by applications or systems, achieving voice interaction and command control functions.

Arduino mega 2560

Arduino mega 2560 is a common microcontroller development board commonly used in the Arduino platform. It is based on the ATmega 2560 chip and has a wealth of input and output pins and features. The Arduino Mega 2560 Development Board is a powerful and flexible tool for various electronic prototype designs and projects. It also has a high storage capacity, including 256 KB flash memory and 8 KB SRAM, which can store Stored procedure code and data. It can achieve various tasks, including controlling robots, driving motors, collecting sensor data, connecting network modules, etc.

Pressure sensor

pressure sensor are devices that measure the pressure of a medium, which can convert physical pressure into electrical signal output. When the medium exerts pressure on the sensing element of the sensor, the sensing element will undergo deformation or compression, thereby changing its resistance, capacitance, or voltage characteristics. Sensors will detect these characteristic changes and convert them into electrical signals proportional to pressure output.

WS2812b display screen

The WS1812B screen, also known as the WS2812B screen, is a commonly used RGB LED strip screen. It comprises multiple WS2812B LED chips, integrating RGB (red, green, blue) LED lights and control circuits. The WS1812B screen usually has flexible connection methods, which can connect multiple screens through a serial connection to form a larger display area. By sending appropriate data signals through the controller, unified or partitioned lighting effects can be achieved on the entire screen.

Relay

A relay is an electrically controlled switching device that controls an electrical signal in one circuit, enabling one or more electrical devices in another circuit to switch. It is an electromagnetic switch composed of an electromagnetic coil and a set of contacts.

LD3320 language recognition module

LD3320 speech recognition module is a module that can achieve speech recognition and speech synthesis. It can achieve human-computer interaction by capturing and processing external sound. LD3320 adopts a special Speech processing chip, which can support multiple languages and voice commands, and has high recognition rate and stability.

ESP8266

ESP8266 Low-cost Wi-Fi module that is a complete Wi-Fi network solution that integrates TCP/IP protocol stack and can communicate with MCU through the serial port. It can also run as an independent MCU. ESP8266 was designed by Lexin Company in China, and its prototype is the Espressif ESP8266EX chip. The ESP8266 module includes a central control chip and some peripheral circuits, including Wi-Fi antennas, crystal oscillators, and peripheral interfaces. The ESP8266 module can be configured and controlled through AT commands and programmed through code. It has multiple operating modes, including soft AP mode, STA mode, AP mode, etc.

Appendix II Programming and coding of Arduino IDE 5.7

Part 1 Basic knowledge of the software refer to chapter 5.7

Figure 8.6 shown below is summarized from self-study for the coding software. The interface is roughly divided into four parts (above image 3): Menu bar: includes file menu, edit menu, program menu, tools menu and help menu.

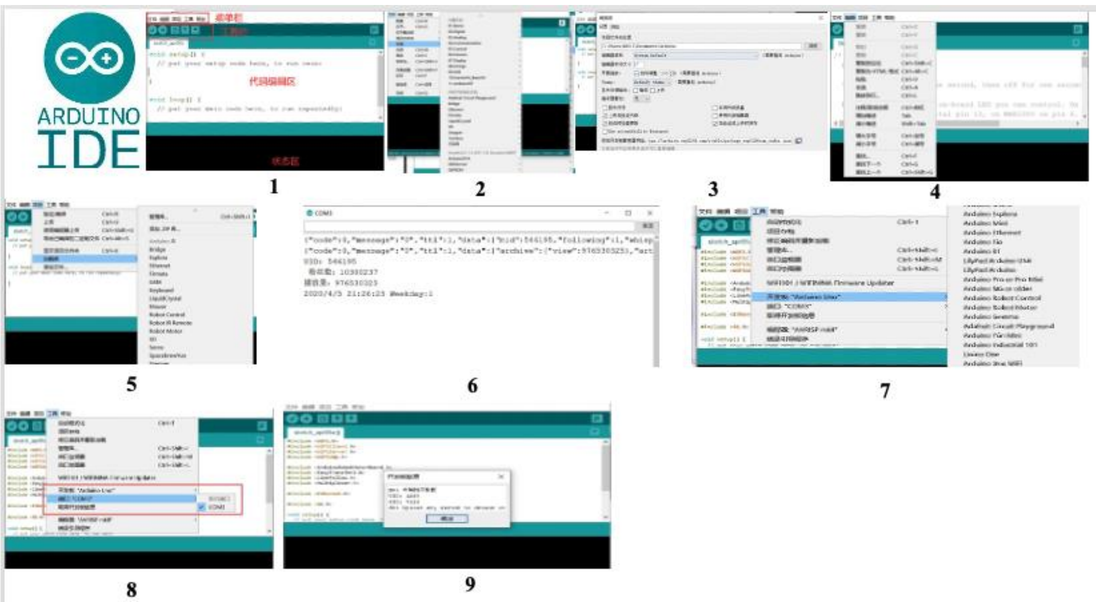


Figure 8.6 Programming and coding process of Arduino IDE

- Toolbar: includes compiling, uploading, creating a new program (sketch), opening program (sketch), Save Program (sketch), and Serial Monitor (Serial) Monitor.
- Editing area: Writing program code area:
- Status area: Display program compilation and upload information; if there are errors in the program, there will be error prompts. Briefly describe the first two parts below:
- Menu bar: File (above image 4) -Example 2: The built-in sample program in the environment can be opened. Arduino comes with a wide range of routines, including basic, digital, analog, communication, display, and more.
- File (above image 5): Preferences: Multiple functions such as selecting the language of the compiler, setting the font size of the compiler, and adjusting the font size of the code can be selected
- Editing (above image 6): Editing, copying, pasting, commenting, indenting, numbering, searching, and other code functions (usually using its corresponding fast key).
- Project (above image 7): Load Library ->Manage Library: You can search and install various support libraries in the network. Select the library you want to install and click Install to download and install it online, which is very convenient.
- Tools (above image 8): Serial Port Monitor: The function of a serial port monitor is to receive

The data Arduino sends to the computer is displayed on the monitor, which can set the acceptable Baud, newline characters, automatic scrolling, etc.

Furthermore, there are a few very useful buttons while coding:

- Compile button to check the correctness of your "syntax" or code. If the code has any Syntax error or undefined transaction volume, there will be an error message at the bottom of the 1DE screen. At the same time, the wrong line of code will be marked with red background color for easy modification. But if it is correct, the message that the editing is completed.
- Upload: The most magical button that allows us to upload programs to Arduino. Although the IDE will compile the code before uploading, it would be better to press the editor key before uploading.
- New: Create a new blank page.
- Open: This button allows you to open an existing draft that you will use when you need to open a downloaded or used file.
- Save: Used to save your draft.
- Serial port monitor: That is, a serial port. The data Arduino sends to the computer can be received and used for debugging code.

Part 2 Instruction in coding refers to chapter 5.7

Coding creation for prototype A

```
Adafruit_NeoPixel.h>
volatile int item;
Adafruit_NeoPixel rgb_display_2 = Adafruit_NeoPixel(150,2,NEO_GRB + NEO_KHZ800);
void setup(){
item = 0;
rgb_display_2.begin();
Serial.begin(9600);
}
void loop(){
//D2 接灯带
rgb_display_2.setBrightness(20);
if (Serial.available() > 0) {
item = String(Serial.read()).toInt();
Serial.println(item);
if (item == 1) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0xff0000));
rgb_display_2.show();
}
}
if (item == 2) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0x3333ff));
rgb_display_2.show();
}
}
if (item == 3) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0x009900));
rgb_display_2.show();
}
}
if (item == 4) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0xffcc00));
rgb_display_2.show();
}
}
if (item == 5) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0xff99ff));
rgb_display_2.show();
}
}
if (item == 6) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0x6600cc));
rgb_display_2.show();
}
}
if (item == 7) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0xff9900));
rgb_display_2.show();
}
}
if (item == 8) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0x3366ff));
rgb_display_2.show();
}
}
if (item == 9) {
for (int i = 1; i <= 150; i = i + (1)) {
rgb_display_2.setPixelColor((i)-1, (0xffffff));
rgb_display_2.show();
}
}
}
}
```

Coding creation for prototype B

```
// 定义继电器引脚

const int relayPins[] = {A0, A1, A2, A3, A4, A5, A6};

const int numRelays = sizeof(relayPins) / sizeof(relayPins[0]);

void setup() {

// 配置继电器引脚为输出模式

for (int i = 0; i < numRelays; i++) {

pinMode(relayPins[i], OUTPUT);

}

}

void loop() {

// 读取模拟口的值，并将其映射到继电器状态

for (int i = 0; i < numRelays; i++) {

int analogValue = analogRead(i);

bool relayState = map(analogValue, 0, 1023, LOW, HIGH);

digitalWrite(relayPins[i], relayState);

}
```

Coding creation for prototype C

```
void setup(){
pinMode(4, OUTPUT);
pinMode(5, OUTPUT);
pinMode(6, OUTPUT);
pinMode(7, OUTPUT);
pinMode(8, OUTPUT);
digitalWrite(4,HIGH);
digitalWrite(5,HIGH);
digitalWrite(6,HIGH);
digitalWrite(7,HIGH);
digitalWrite(8,HIGH);
pinMode(9, INPUT);
pinMode(13, OUTPUT);
pinMode(10, INPUT);
pinMode(11, INPUT);
pinMode(12, INPUT);
pinMode(3, INPUT);
Serial.begin(9600);
}
void loop(){
if (digitalRead(9) == 1) {
digitalWrite(4,LOW);
NewTone(13,532,5000);
} else {
digitalWrite(4,HIGH);
}
if (digitalRead(10) == 1) {
digitalWrite(5,LOW);
NewTone(13,532,5000);
} else {
digitalWrite(5,HIGH);
}
if (digitalRead(11) == 1) {
digitalWrite(6,LOW);
NewTone(13,532,5000);
} else {
digitalWrite(6,HIGH);
}
if (digitalRead(12) == 1) {
digitalWrite(7,LOW);
NewTone(13,532,5000);
} else {
digitalWrite(7,HIGH);
}
if (digitalRead(3) == 1) {
digitalWrite(8,LOW);
NewTone(13,532,5000);
} else {
digitalWrite(8,HIGH);
}
Serial.println(String(digitalRead(9)) + String(digitalRead(10)) + String(digitalRead(11)) + String(digitalRead(12)) + String(digitalRead(3)));
```

Appendix III Questionnaire Samples 6.1

Part 1, Questionnaire sample for kindergarten trial experiment

The questionnaire below shows one set of forms for a participant who joined the trial experiment for play experience on both play mats A&B. The form includes a cover page, one page of play mat Form A, and one page of play mat Form B, a total of 3 pages for each participant. The observer (teacher or adult assistant) judged by observing the participant's reaction and filling out the form, and finally evaluated by the researcher at the end when all data was collected.

主办机构：THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學 iWEAR RESEARCH INSTITUTE FOR INTELLIGENT WEARABLE SYSTEMS

1-3 岁幼儿互动地毯试玩调查问卷

互动型运动游戏地毯试玩调查	商用运动游戏毯试玩调查
人数：2 名幼儿为一组，一男一女，共 3 组	人数：2 名幼儿为一组，一男一女共 3 组
时长：每组 30 分钟	时长：每组 30 分钟
游戏测试内容：有四名成人主持人在场，每名幼儿配一名成人一对一地进行观察游玩测试并拍照记录同时保障幼儿安全。期间，有一名主要主持人维持秩序，另一人监控技术（录像和相关电器的正常运作）。录像机可以提早定点在房间四周。这些幼儿中没有一个见过要测试的互交环境，他们也不属于帮助开发这些技术的设计团队。此游戏测试主要观察幼儿在互动型运动地毯上自发性随心玩耍过程中幼儿的反应和玩耍时长。	游戏测试内容：有四名成人主持人在场，每名幼儿配一名成人一对一地进行观察游玩测试并拍照记录同时保障幼儿安全。期间，有一名主要主持人维持秩序，另一人监控技术（录像和相关电器的正常运作）。录像机可以提早定点在房间四周。这些幼儿中没有一个见过要测试的环境，他们也不属于帮助开发这些技术的设计团队。此游戏测试主要观察幼儿在商用运动游戏毯上自发性随心玩耍过程中幼儿的反应和玩耍时长。

备注：所有调查内容只供内部研究使用

Figure 8.1 Cover of the questionnaire

问卷 A 幼儿互动型游戏运动毯

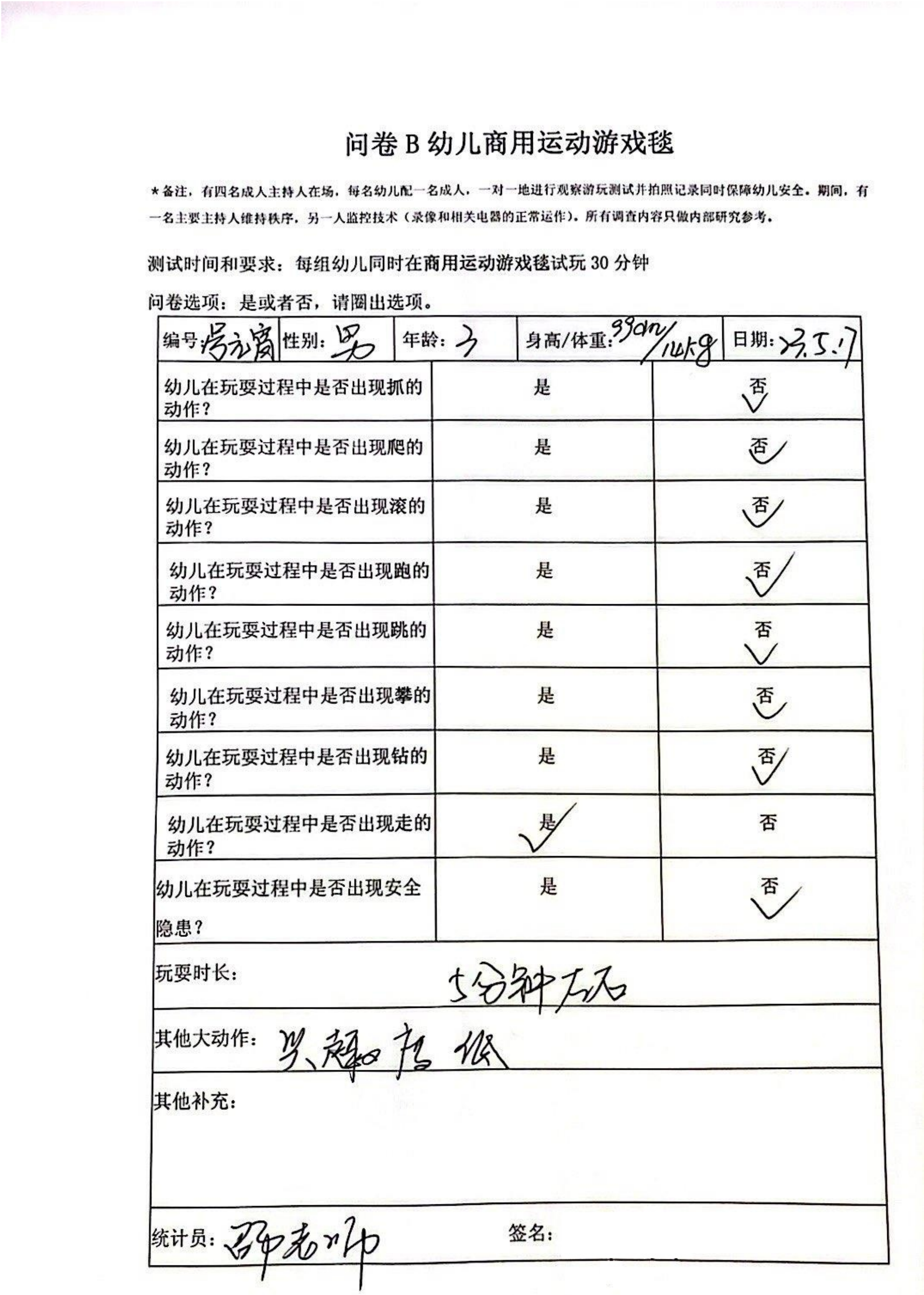
*备注，有四名成人主持人在场，每名幼儿配一名成人，一对一地进行观察游玩测试并拍照记录同时保障幼儿安全。期间，有一名主要主持人维持秩序，另一人监控技术（录像和相关电器的正常运作）。所有调查内容只做内部研究参考。

测试时间和要求：每组幼儿同时在互动型运动游戏毯试玩 30 分钟

问卷选项：是或者否，请圈出选项。

编号：吕元宵	性别：男	年龄：3	身高/体重：99cm/14kg	日期：23.5.17
幼儿在玩耍过程中是否出现抓的动作？	是✓		否	
幼儿在玩耍过程中是否出现爬的动作？	是✓		否	
幼儿在玩耍过程中是否出现滚的动作？	是✓		否	
幼儿在玩耍过程中是否出现跑的动作？	是✓		否	
幼儿在玩耍过程中是否出现跳的动作？	是✓		否	
幼儿在玩耍过程中是否出现攀的动作？	是✓		否	
幼儿在玩耍过程中是否出现钻的动作？	是✓		否	
幼儿在玩耍过程中是否出现走的动作？	是✓		否	
幼儿在玩耍过程中是否出现安全隐患？	是		否✓	
玩耍时长：30分钟左右				
其他大动作：手脚并用的方式安全的爬攀				
其他补充：喜欢数字、对音乐敏感度强				
统计员：邵老师		签名：		

Figure 8.2 Form A of the questionnaire.



问卷 B 幼儿商用运动游戏毯

*备注，有四名成人主持人在场，每名幼儿配一名成人，一对一地进行观察游玩测试并拍照记录同时保障幼儿安全。期间，有一名主要主持人维持秩序，另一人监控技术（录像和相关电器的正常运作）。所有调查内容只做内部研究参考。

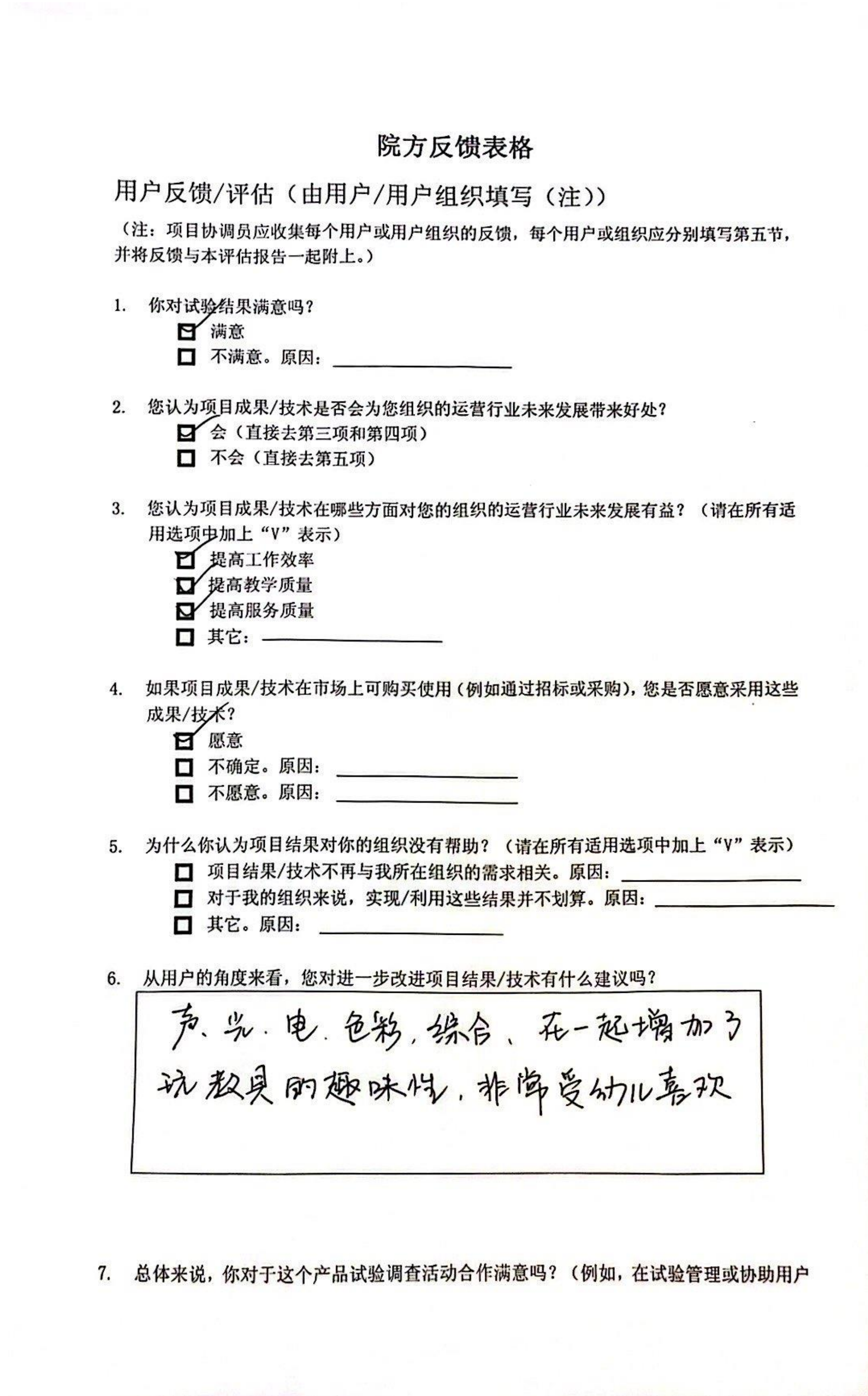
测试时间和要求：每组幼儿同时在商用运动游戏毯试玩 30 分钟

问卷选项：是或者否，请圈出选项。

编号：[illegible] 性别：男	年龄：3	身高/体重：99cm/16kg	日期：23.5.17
幼儿在玩耍过程中是否出现抓的动作？	是	否 ✓	
幼儿在玩耍过程中是否出现爬的动作？	是	否 ✓	
幼儿在玩耍过程中是否出现滚的动作？	是	否 ✓	
幼儿在玩耍过程中是否出现跑的动作？	是	否 ✓	
幼儿在玩耍过程中是否出现跳的动作？	是	否 ✓	
幼儿在玩耍过程中是否出现攀的动作？	是	否 ✓	
幼儿在玩耍过程中是否出现钻的动作？	是	否 ✓	
幼儿在玩耍过程中是否出现走的动作？	是 ✓	否	
幼儿在玩耍过程中是否出现安全隐患？	是	否 ✓	
玩耍时长：5分钟左右			
其他大动作：[illegible]			
其他补充：			
统计员：[illegible]	签名：		

Figure 8.3 Form B of the questionnaire.

Part 2, Questionnaire sample for the principal of the kindergarten



院方反馈表格

用户反馈/评估（由用户/用户组织填写（注））

（注：项目协调员应收集每个用户或用户组织的反馈，每个用户或组织应分别填写第五节，并将反馈与本评估报告一起附上。）

1. 你对试验结果满意吗？
   - ☑ 满意
   - ☐ 不满意。原因：＿＿＿＿＿＿

2. 您认为项目成果/技术是否会为您组织的运营行业未来发展带来好处？
   - ☑ 会（直接去第三项和第四项）
   - ☐ 不会（直接去第五项）

3. 您认为项目成果/技术在哪些方面对您的组织的运营行业未来发展有益？（请在所有适用选项中加上“V”表示）
   - ☑ 提高工作效率
   - ☑ 提高教学质量
   - ☑ 提高服务质量
   - ☐ 其它：＿＿＿＿＿＿

4. 如果项目成果/技术在市场上可购买使用（例如通过招标或采购），您是否愿意采用这些成果/技术？
   - ☑ 愿意
   - ☐ 不确定。原因：＿＿＿＿＿＿
   - ☐ 不愿意。原因：＿＿＿＿＿＿

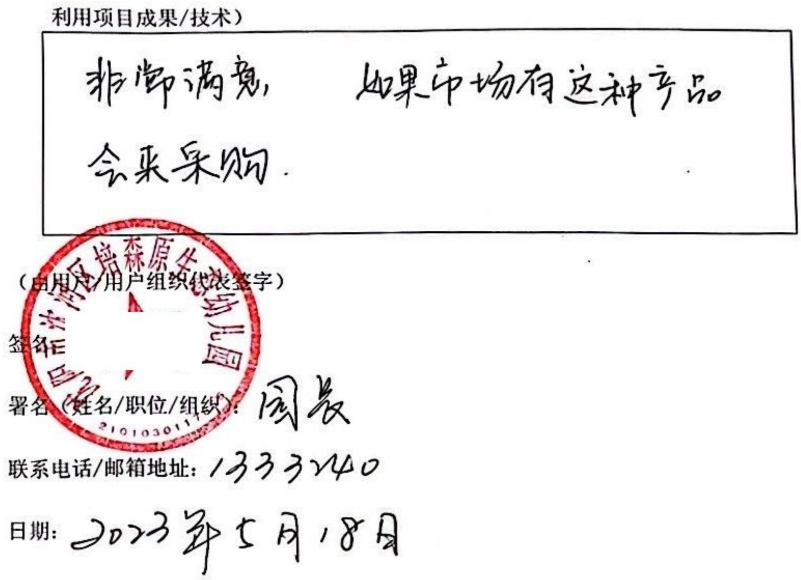
5. 为什么你认为项目结果对你的组织没有帮助？（请在所有适用选项中加上“V”表示）
   - ☐ 项目结果/技术不再与我所在组织的需求相关。原因：＿＿＿＿＿＿
   - ☐ 对于我的组织来说，实现/利用这些结果并不划算。原因：＿＿＿＿＿＿
   - ☐ 其它。原因：＿＿＿＿＿＿

6. 从用户的角度来看，您对进一步改进项目结果/技术有什么建议吗？

   声、光、电、色彩、综合、在一起增加了玩教具的趣味性，非常受幼儿喜欢

7. 总体来说，你对于这个产品试验调查活动合作满意吗？（例如，在试验管理或协助用户

Figure 8.4 Questionnaire for principal



利用项目成果/技术）

非常满意，　如果市场有这种产品会来采购.

（[illegible]用户/用户组织代表签字）

签名：

署名（姓名/职位/组织）：园长

联系电话/邮箱地址：1333240

日期：2023年5月18日

Figure 8.5 Questionnaire for principal

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