

DESIGN IMPROVEMENT FOR A DIGITAL MANIPULATIVE BLOCK SET, *LIBLO* THROUGH USABILITY TESTING

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ABSTRACT

Today, ICT is being embedded in everyday objects intended for use with various products and services. In education, digital manipulative blocks are educational tools resulting from the convergence with ICT. However, current blocks are not suitable to create various kinetic forms, so new digital operation blocks are needed to create various kinetic forms. *Liblo* is a set of digital manipulative block with built-in ICT. We are developing the *Liblo* as a long term project. In previous studies, we designed and developed the first prototype of *Liblo*. This research aims to improve our *Liblo* design based on design feedback from usability tests. In this paper, we present how to apply the usability testing in order to improve the *Liblo* design and finally propose newly re-designed *Liblo*. Currently, we are developing the newly re-designed *Liblo*. In further research, we will provide developmental experiences of the new *Liblo* and how to evaluate it. This study contributes to designers or/and developers who are developing digital manipulative block sets by guiding *Liblo* through the design improvement process.

Keywords: *Usability Testing, Liblo, Design Improvement, Digital Manipulative Block Set, Design Thinking*

1. INTRODUCTION

Today, we can easily find everyday objects embedded with information and communication technology (ICT) [1]. Recently, ICT-based products and services have brought about changes in social, economic, and educational areas [2]. In particular, contemporary education for creativity requires smart, connected educational tools to quickly and easily embody robots and various working forms because these tools enable children to gain a better understanding of modern technologies [3]. Accordingly, ICT-based products have emerged in education [4]. Among such products, traditional blocks that support both individual learning and collaboration have evolved through an integration with ICTs, such as sensors, actuators, and communication devices [5]. However, previous digital manipulative block sets do not meet all requirements for high formability, high freedom of movement and low assembly difficulty. Therefore, new ICT-based digital manipulative block sets are needed to easily create various kinetic forms [6].

As a long term project, we are developing a new digital manipulative block set based on ICT and Robotics, called *Liblo*. *Liblo* aims to allow students

to enhance creativity through the process of designing and creating kinetic forms themselves [7]. To achieve this purpose, we began by establishing a process to create kinetic forms through different experiments. Moreover, we investigated the latest cases of digital manipulative block sets to understand their current situations and problems [3]. As such, *Liblo* was designed by repeating the prototype-test-improvement process based on a design thinking process [8]. In addition, we developed technology to implement *Liblo* [6].

Liblo, as our first working prototype, consists of a 26-sided shape, and students can create various forms by attaching different blocks on one side. In addition, we added passive blocks to combine basic *Liblo* block in order to provide various coupling angles.

Liblo, developed within design thinking, is currently in the stage of usability tests since designers and/or developers perform usability tests to determine how people actually use products within design thinking [9].

The purpose of this study is to improve the design of *Liblo* based on design feedback from usability tests. For this study, we firstly explore

cases about existing digital manipulative block sets for extracting evaluation elements. Also, we investigate literature related to usability tests and, based on this, construct methods and questions for *Liblo* usability testing. After *Liblo* usability testing, we classify and summarize the design feedback derived from the results of the usability tests. In addition, we draw insight into design improvements through internal workshops and modify our *Liblo* based on this insight. In this paper, we finally propose newly re-designed *Liblo*.

In this paper, we present methods to improve *Liblo* design and their experience. Thus, this study contributes to help designers fully explore methods to effectively develop digital manipulative block sets through a prototype-test process based on design thinking.

This paper consists of 7 chapters, including this chapter that introduces the background, purpose, and method of this research. In the second chapter, we review literature and explore cases related to existing digital manipulative blocks. In the third chapter, *Liblo* developed so far is summarized based on its concept, development purpose, and composition. The fourth chapter shows *Liblo*'s usability testing methodologies, execution environments, and test results. The fifth chapter describes methods to improve design depending on usability test results. In the sixth chapter, we show how the design improvements are actually applied to *Liblo*. The seventh chapter concludes this paper with a review and limitations of this research and further research.

2. DIGITAL MANIPULATIVE BLOCK SET

A digital manipulative block set can not only construct a variety of shapes through combination of blocks, but can also add digitally-driven functions such as motion, sensing, and light to them. This allows children to create robots and devices that respond and act on their own [10]. In education, digital manipulative blocks help students become interested in robotics education by supporting the process of creating and programming robots [3]. In this chapter, we investigated cases about a digital manipulative block sets to derive evaluation elements.

Lego Mindstorms is widely used as a representative digital manipulative block set [11]. Lego Mindstorms consists of rotatable motor blocks, sensor blocks, various types of passive blocks, and a programming brick that can control

these blocks. The children can create various robots and devices by using blocks with different shapes and functions. However, because active and semi-active blocks of Lego Mindstorms have same colors, it is difficult for children to quickly and intuitively select the active blocks that they want. In addition, a motor block, a sensor block, and a programming brick are not modularized. This makes it hard to replace or repair when some interlocking parts or parts of the blocks are damaged.

Tinkerbot consists of a power brain block that provides power for other blocks, triangle blocks with various angles, and five motion blocks that provide different movements each other [12]. Tinkerbot are easy to assemble its blocks because joints of the blocks are unified. However, Tinkerbot is not easy to quickly and intuitively assemble the blocks because the five motion blocks are same in gray.

Cubelets is composed of a cube-shaped blocks with different functions [13]. Users can quickly build various forms by combining blocks of a same shape. Moreover, users can broadly recognize blocks with colors according to functions such as input, output, and control. However, this makes it difficult to distinguish between blocks with similar functions because of the same shape. In addition, several blocks don't provide intuitive interfaces in the process of joining the blocks since parts connecting other blocks and parts providing motion are easily not distinguished.

Moss consists of a cube-shaped passive block, two movable blocks, a sensor block, a flexible line block and accessories for angle conversion and a configuration [14]. Moss has different colors in junction parts according to four functions such as 'power', 'data in', 'data out,' and 'pass through.' In this way, users can intuitively join blocks that they want. However, Moss is hard to quickly assemble blocks because one block has several interlocking parts.

Topobo is composed of passive blocks with five angles and shapes and streamlined active blocks capable of rotating [15]. Passive blocks have different colors according to their shape and active blocks that provide motion are also differentiated from passive blocks in a color. However, Topobo has limitations in configuring and extending various motions.

Linkbot consists of a semi-cylinder block and various accessories [16]. The semi-cylinder block has three hubs that provide a rotational motion. The

accessories have various shapes and functions such as wheels and connectors. The Linkbot provides intuitive interfaces in a shape and a color. However, since Linkbot's hubs only provide rotational motion, it is difficult to implement and extend various movements.

Currently, digital manipulative block sets include one or more of four limitations as follows: 1) it is difficult for users to intuitively distinguish between blocks according to functions, 2) it is hard for users to quickly assemble blocks, 3) it is not easy to replace or repair damaged joints, and 4) users have some limitations in creating various shapes with movements.

3. LIBLO

Liblo, refers to our new digital manipulative block set, and it is a portmanteau of “living blocks” [7]. These blocks are meant for use as an educational tool in contemporary STEAM (Science, Technology, Engineering, Art, and Mathematics) education, emphasizing the ability to create new things in interdisciplinary contexts [17]. For this reason, we designed *Liblo* for students to quickly and easily design kinetic forms. To support the

design of various kinetic forms, three conditions are required, including high formability, high freedom of movement, and low assembly difficulty. Under such conditions, we configured *Liblo* into active blocks, semi-active blocks, and passive blocks according to flowing data and supplying power.

First, the active blocks consist of a main block that controls other blocks and a power block that supply additional power. Second, the semi-active blocks consist of kinetic blocks, sensor blocks, and line blocks. The kinetic blocks that implement motion are composed of a rotation, pivot, and piston motion, which can be combined with each other. In addition, the main block and kinetic blocks are each made up of 26-sided shapes, which can be joined at various angles. The main blocks and kinetic blocks are considered as basic blocks. Third, passive blocks are designed to allow users to combine various forms easily and quickly. Therefore, passive blocks can be bonded to a basic block, and they contain special features or shapes that active blocks and semi-active blocks do not have. Moreover, users can utilize Lego blocks instead of our passive blocks because *Liblo* is compatible with Lego. Figure 1 shows a composition of *Liblo* [7].

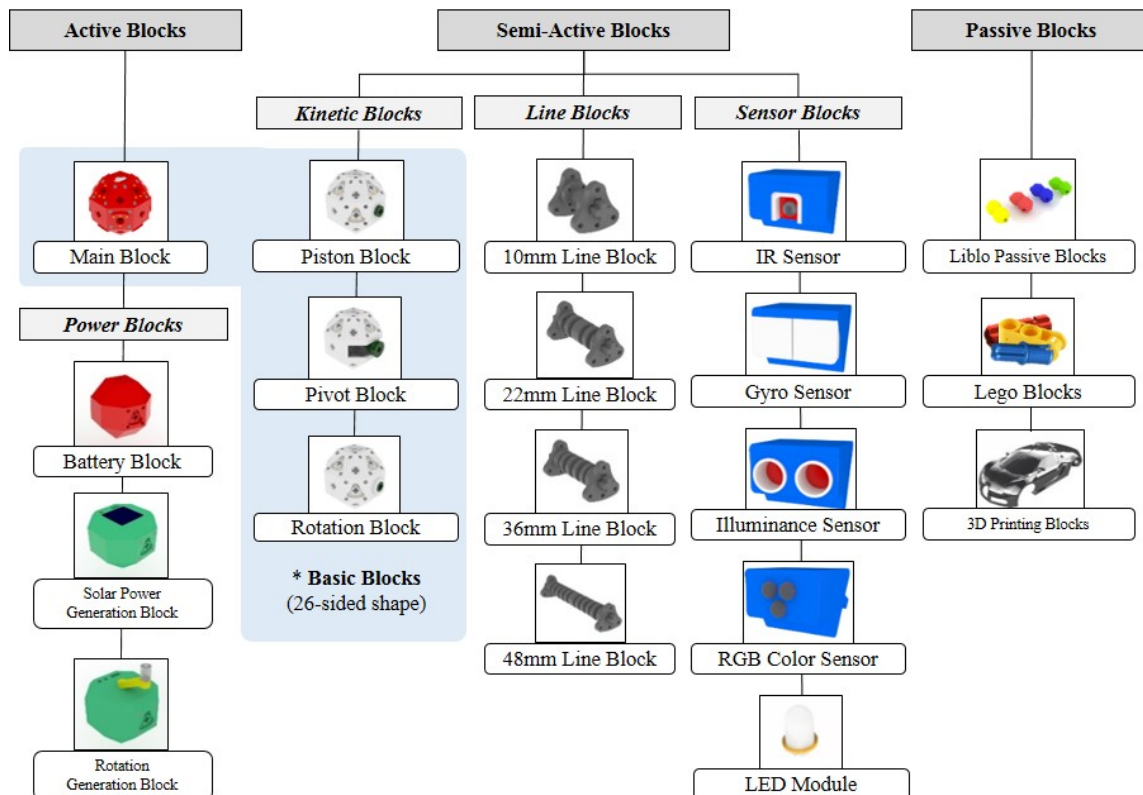


Figure 1: Composition of Liblo

4. USABILITY TEST

A usability test is conducted to gain insight into how people use the product [18]. In addition, usability tests can be performed during product development to prevent problems with the finished product [19]. For this reason, companies and organizations are adopting new product development processes following 'prototype-test-improvement' methods, which are faster and can be conducted at a lower cost [20]. *Liblo* was developed using a design thinking process that pursues creative problem solving through user-centered observations, questions, ideas, and tests. During design thinking, usability tests take a total of 7 steps [21], and we have built a usability test process based on a seven-step feedback process. Table 1 shows the main contents of the 'receive feedback' process during design thinking.

Table 1: Main Content of the 'Receive Feedback' Process in a Design Thinking Process.

Process	Details
Identify Sources for Feedback	- Consider a usability testing environment - Define and refine tests
Select Feedback Participants	- Selecting participants - Interaction and action plans
Build a Question Guide	- Structuring the questions - Organizing the question guide
Facilitate Feedback Conversations	- Induce the atmosphere - Keep neutral and edit in the field
Capture Feedback Learnings	- Seize ideas for design modifications - Share your feelings
Integrate Feedback	- Classify your feedback - Assess relevance - Modify prototype
Identify What's Needed	- Materializing - Predict time and budget, finding participants - Action plan

4.1 Method

We conducted usability test for key users of *Liblo* [22]. We attempted to identify three things: 1) how students use basic blocks, 2) how students assemble basic blocks and passive blocks, and 3) how students create movement. For this purpose,

we divided the usability test process into 6 steps. First, we defined a usability testing environment and defined the goals of the test. Our usability testing environment was chosen to test and run the actual blocks in a typical home. The goal of the test was to assess how well students are using *Liblo*. Second, we selected usability test participants as a group of boys aged 10 to 15, the main users of the *Liblo*. We use both methods to interview students and observe task performance because it is difficult for boys aged 10 to 15 to provide feedback directly to the block design. Third, we structured the question into three sessions and created a question guide. Table 2 shows the question guide used in the usability test. Fourth, we visited the student's home and conducted a usability test. The usability test time was 2 hours considering the time students could concentrate on. All the usability tests were recorded with a digital camera. Figure 2 shows the usability testing environment of *Liblo*. Fifth, we conducted an internal workshop within 24 hours and shared opinion on design feedback derived from the usability test.

Table 2: Question Guide of the Liblo Usability Test.

Session 1. Pre-Testing	
Subject	(1) Design freely
Action	(1) Make anything freely
Session 2. Instructions	
Subject	(1) Creating research environment (2) Level of understanding of the block (3) First impression of block design (4) Function of block (5) Method of joining blocks (6) Function learning
Action	(1) Introduction of greetings and experiments (2) Asking about dealing with blocks (3) Ask about first impressions (4) Look at the block to see the feature (5) Guess how it joins (6) Introducing the function of the block
Session 3. Main Testing	
Subject	(1) Contour shaping (2) Function-based molding (3) Behavior configuration (4) Atypical morphogenesis
Action	(1) Making a favorite animal (2) Making a moving car (3) Creating a car to change direction (4) Create a monster that is not in the world



Figure 2: Usability Testing Environment of Liblo.

4.2 Results

Our usability tests were conducted in 6 steps for 2 hours. The participants were impressed with *Liblo's* new design. However, we were able to spot some pain points at the moment when students were having difficulty performing usability test tasks. After the usability test, we shared our thoughts on observations and pain points when students manipulated *Liblo* through an internal workshop. The results of the analysis of linkages to these observations during the usability test with the first prototype of *Liblo* could be classified into 1) forms, 2) movements, 3) assembly. Table 3 shows the results of the usability test [16].

5. DESIGN IMPROVEMENT SUGGESTIONS FOR *LIBLO*

The usability tests provided design feedback for

Liblo's first prototype. The design feedback and insights are derived from an internal workshop with observers after the usability testing. Based on design thinking, we selected the most important design feedback to quickly repeat the process to improve the prototype and return to the test process. The main design feedback we selected are: 1) Students often did not use the bottom sides of the basic blocks, mainly using other sides to work with kinetic blocks. 2) Students could not use the junction of the main block and the kinetic block separately. 3) If one side of the block is damaged, the block is unusable or very difficult to replace. We brainstormed how to draw design improvement ideas to solve these three problems. A design improvement suggestions were derived by considering the development process of *Liblo* and internal hardware. Figure 3 shows the design feedback from the usability test and the design ideas to improve it.

Table 3: Results of the Usability Test.

1) Forms	<ul style="list-style-type: none"> - Students used the other side of the block to create a motionless form. - Students did not use the top and bottom sides of the <i>Liblo</i> when creating kinetic forms. - When creating a standard form, students used different blocks, such as blocks and Lego technical parts. - Students did not use other blocks to create non-standard forms.
2) Movements	<ul style="list-style-type: none"> - Students focus on making movements using kinetic blocks rather than shapes. - Students did not distinguish between kinetic blocks. - Students were trying to assemble basic blocks instead of using passive blocks when creating kinetic forms.
3) Assembly	<ul style="list-style-type: none"> - Students tended to assemble blocks without considering the details of the blocks. - Students had difficulty assembling block and Lego technical parts. - During usability testing, a block could not use one complete block if one side was broken.

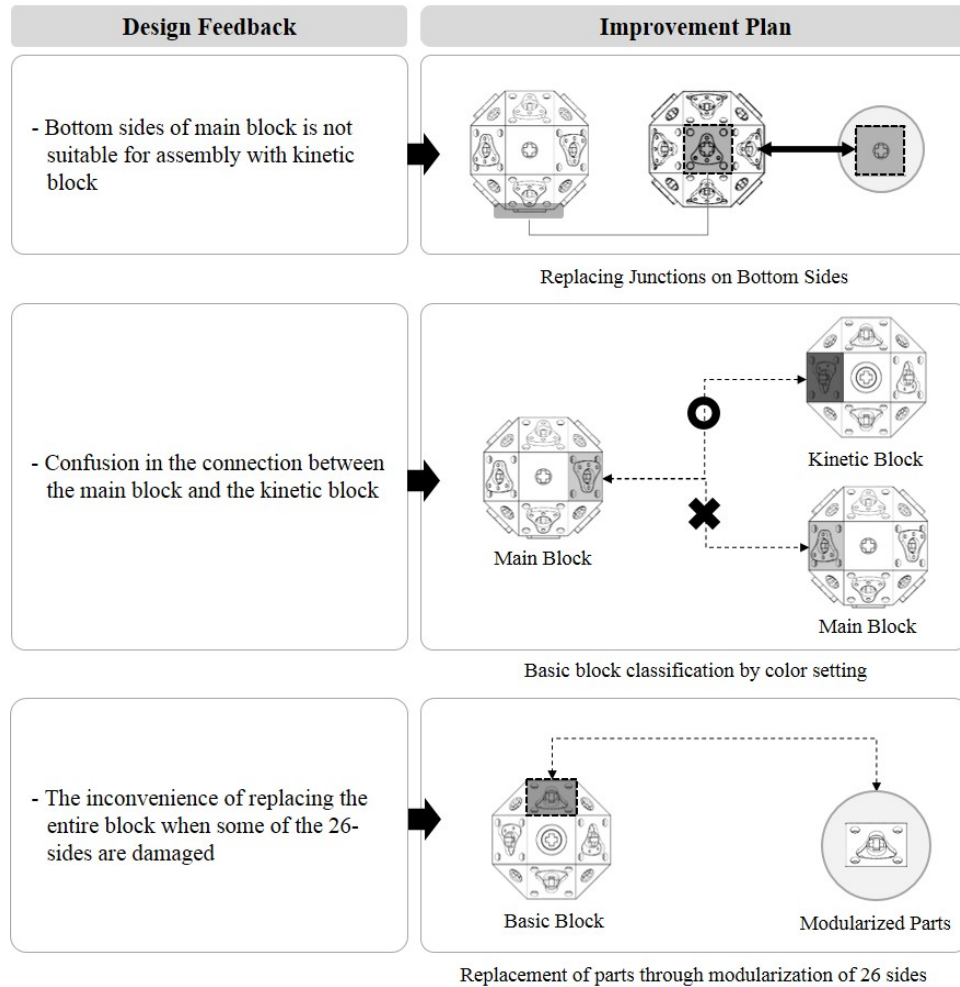


Figure 3: Design Improvement Plan for the Liblo.

6. IMPROVEMENT DESIGN

We began to modify *Liblo* design through rebuilding 3D models of *Liblo* based on the design improvement suggestions.

Firstly, we modified a bottom sides of basic blocks for connecting passive blocks instead of kinetic blocks because students do not use them. As this modification enables students to only join passive blocks in the bottom sides of basic blocks, students can quickly, and easily assemble blocks without any confusion. Also, we secured an internal space of basic blocks, into which electronic parts can be embedded. Figure 4 shows the improvement design of a main block.

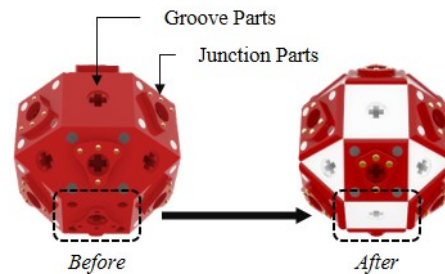


Figure 4: Improvement Design of a Main Block.

For effectively repairing blocks, we modularized active blocks and semi-active blocks with junction parts. The basic blocks of a 26-sided shape consist of block body and junction parts. The block body are divided into three modules: an upper part, a middle part, and a lower part. These block body includes grooves capable of inserting passive blocks. The junction parts are composed of a male

part and a female part. Figure 5 shows the composition of a main block.

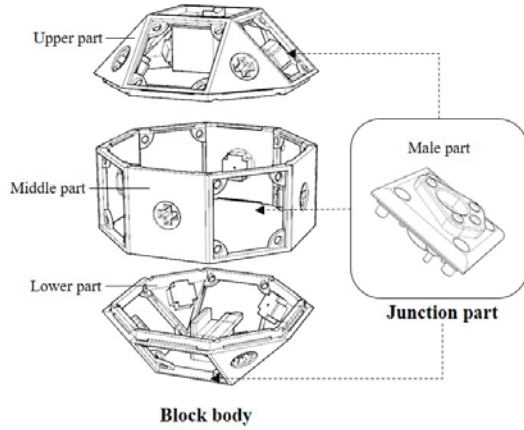


Figure 5: Composition of a Main Block.

In order to enable users to intuitively distinguish basic blocks, we used different colors to basic blocks: a main block is white, a piston block is green, a pivot block is yellow, and rotation block is blue. Moreover, for helping users understand the flow of data and a current in blocks, we put a red color on junction parts. Figure 6 illustrates the junction parts that consist of a male part and a female part.

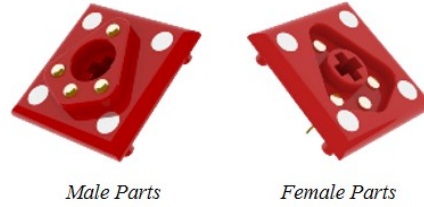

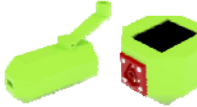


















Figure 6: 3D Models of Junction Parts

Table 4: Newly Re-designed Liblo

Block	Name	Previous Liblo	Re-designed Liblo	
Active Blocks	Power Blocks			
	Battery Block			
	Main			
Semi-Active Blocks	Piston			
	Pivot			
	Rotation			
	-	Sensor Blocks		
	-	Line Blocks		
Passive Blocks	-	Liblo Passive Blocks		

Based on these modifications, we modeled and rendered newly re-designed *Liblo* by a commercial 3D computer graphics application, Rhinoceros 3D. Table 4 shows the newly re-designed *Liblo*.

7. CONCLUSIONS AND FURTHER RESEARCH

This study aims to improve the design of *Liblo*'s prototype based on the results of the usability test. To achieve this goal, we implemented a design improvement based on a prototype-test-improvement iterative process with design thinking. The six-step usability testing process showed design issues for *Liblo* including: 1) students could not distinguish between the main block and the kinetic block of *Liblo*. 2) *Liblo* junctions are not intuitive enough to make irregular shapes and are inconvenient. 3) If one of the block sides is damaged, the block is unusable or very difficult to replace.

To solve these problems, we propose design improvement suggestions for *Liblo* as follows: 1) designing to join the kinetic blocks at the bottom of the main block with a change to a design that can be bonded to the passive block, 2) applying different colors to the basic blocks so that students can distinguish the blocks intuitively, and 3) Modularizing the active blocks and semi-active blocks with junction parts in order to quickly and easily replace parts during development. Based on the design improvement suggestions, we re-designed *Liblo* through re-building 3D models of *Liblo*. *Liblo* will provide a more intuitive interface to users through the design improvement.

This paper presents a method to improve our *Liblo* design and its experience. Thus, this study will contribute to help designers fully investigate a method to effectively design and develop a set of digital manipulative block within design thinking. This research has some limitations in that our redesign *Liblo* is not evaluated and developed as a working prototype.

Thus, further research of this study is to develop improved prototypes reflecting the design improvements of this study and evaluate its user experience (UX) in different test environment.

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