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Impact of Gamified Learning Using Smart Building Blocks on Early Childhood Development

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The focus of this study lies in early childhood development, a crucial stage marked by sensorimotor and cognitive advancements. The trajectory of early childhood development is intricately influenced by genetics, environment, nutrition, health, and, notably, stimulation, which is the provision of enriching sensory and educational encounters. Toys emerge as one of the vital catalysts for nurturing exploration, creativity, and learning in children. The efficacy of toys varies, prompting the imperative to craft age-appropriate, technology-aligned playthings. Smart toys, exemplified by smart building blocks, seamlessly blend conventional play with electronic components, promising interactivity and amusement. In this research, whether game-infused learning, employing these smart building blocks, augments early childhood development is investigated and its pedagogical efficacy is assessed through educational effectiveness evaluation. Notwithstanding certain constraints, encompassing cost considerations, technological functionalities, and regional predispositions, in this investigation, innovative paradigms are introduced for shaping smart building blocks as didactic implements that prioritize simplicity over intricate technology. The findings underscore the ease of use and educational potential intrinsic to smart building blocks, positioning them as transformative assets in early childhood education. Consequently, this exploration advocates further research and development to unlock their complete educational prowess.

1. Introduction

Gamification is the application of game elements and mechanics in non-game settings such as education, health, and business to enhance motivation, engagement, learning, and behavior change. Gamification has been widely used in various fields and has shown positive effects on various outcomes.(1–3) In recent years, more and more scholars have begun to study the impact of gamification on children's early development.(4–6)

Early childhood is a critical period for human sensorimotor development as it is a time during which the foundation for lifelong learning, well-being, and productivity is laid. It is followed by

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the preoperational stage, in which cognitive, social, and emotional growth and changes are explored in a self-centered manner.(7) Early childhood development is affected by many factors, such as genetics, environment, nutrition, health, and stimulation. Among them, stimulation refers to providing appropriate and diverse sensory and learning experiences that can enhance children's brain development and cognitive abilities.(8)

Toys are one of the most common and effective sources of stimulation for children. Toys can provide children with opportunities to explore, discover, create, play, and learn in fun and enjoyable ways. Toys can also promote children's physical, cognitive, social, and emotional development by enhancing, for example, their motor skills, language skills, logical thinking, spatial awareness, creativity, imagination, problem-solving abilities, and self-regulation. However, not all toys are equally beneficial to a child's development. Some toys may be too simple or too complex for a child's age and stage of development. Choosing age-appropriate toys ensures that the toys will serve their purpose.(6)

Therefore, there is a need to design effective toys that are suitable for children's development and in line with technological trends. One possible way to achieve this is through smart toys. Smart toys combine traditional toys with electronic components to achieve the function of detecting or responding to various stimuli. Smart toys and smart building blocks can provide children with more interactivity and fun. However, regardless of whether or not the toys incorporate technology, toys and smart toys must be fun in nature.(4)

The purpose of this study is to explore the impact of game-based learning on early childhood development through the use of smart building blocks. In this study, gamified learning was applied in the context of smart bricks, which were used as learning tools for children.

In this study, we explore whether game-based learning with smart building blocks can help children's early development, and we evaluate its effectiveness through educational effectiveness evaluation. The limitations of this study are as follows.

(1) Through a pretest questionnaire, it was found that smart building blocks are too expensive, so a design that accommodates a price that consumers prefer was devised.
(2) Since the price of the designed blocks is lower than that of the expensive smart building blocks on the market, they do not provide comprehensive smart functions.
(3) The target group of this study is children aged 5–10. To meet the needs of this age group, the technological functions of the designed smart building blocks are only three and do not require users to write programs.
(4) The subjects in this study are from southern Taiwan, and there may be different biases for subjects in other regions.

The innovations and contributions of this study are as follows.

(1) The results of this study provide new ideas for designing and using smart building blocks as children's learning tools. High-end technology should not be pursued as it makes the operation of smart building blocks difficult.
(2) This paper contributes to the literature on gamification, smart toys, and early childhood development.

2. Literature Review

2.1 Childhood development theory

Educational psychology provides an understanding of learning and development in the educational process, and this theories typically focus on the cognitive, emotional, and social development of children and students. However, with further research, people began to realize that young children have unique needs in their physical and psychological development. The cognitive, emotional, and physiological characteristics of young children are significantly different from those of adults and older children. This recognition led to the emergence of developmental psychology for young children. Therefore, the theoretical framework of educational psychology has been adjusted and expanded to gain a deeper understanding of the special needs of young children and emphasizes the uniqueness of their development. Piaget's theory of cognitive development explains how a child constructs a mental model of the world.(9) He disagreed with the idea of intelligence being a fixed trait, and regarded cognitive development as a process that occurs as a result of biological maturation and interaction with the environment. Hence, Piaget proposed the theory of cognitive development in young children, and divided the development into four stages.(7) Young children actively engage with their environment, constructing their cognitive structures. Among these stages, children aged 7 to 11 begin to think logically about concrete events, developing more logical and organized thinking and the ability to infer specific information to general principles. Erikson proposed the theory of psychosocial development, emphasizing the psychological and social development of young children. He emphasized the interplay between individual identity and social interactions for children at different stages.(10) Vygotsky proposed the theory of cultural development; he believed that the social and cultural environment is crucial for the development of children, particularly their language abilities. Effective social interaction is seen as a facilitator of cognitive and thinking skills in young children.(11) It not only affects educational practice, but also profoundly affects the understanding of early childhood development.

2.2 Multiple intelligence theory

With the advancement of science and technology, society has higher and more comprehensive requirements for children's education awareness. Before the 1980s, human intelligence had only one type of intelligence that could be measured by standardized tests. Howard Gardner identified seven intelligences, leading to the multiple intelligence (MI) theory.(8) However, in the educational environment at that time, which focused solely on intellectual education, his MI theory was not recognized by mainstream academics, and creative teaching did not become well established in the education field. In response to this educational resistance, an eighth intelligence called naturalist was proposed by Gardner. These eight intelligences are identified as linguistic, logical-mathematical, spatial, bodily-kinesthetic, musical, interpersonal, intrapersonal, and naturalist.(12,13) According to MI theory, the naturalist promotes creativity during instruction, requiring students to complete creative assignments and to develop problem-solving and critical-thinking skills. An instruction environment encouraging discovery learning would increase students' learning motivation and develop their creativity.(13)

In countries where English is not the native language, how to help students learn English better has long been a problem challenging school teachers and parents. The teacher's explanations always dominate the classroom. Students only listen and take notes, but do not actively participate in classroom teaching. This passive learning method has greatly affected students' enthusiasm and initiative in learning English, causing a large number of students to lose interest in learning English and even to become disgusted with it. Therefore, some teachers use MI theory for foreign language teaching and have achieved good results.(14–17) In addition to English learning, using MI theory can also have a positive impact on general subjects.(18) It also has very good effects on the development of multiple intelligences of the preschool-aged child.(19) It is even helpful for young children with disabilities.(20)

2.3 Gamified learning based on MI theory

In MI theory, playing, dreaming, and imitating in childhood are learning methods that optimize the learning process through game elements.(21) Learning while playing has now been made a part of the educational curriculum. For children, toys, as the main carrier of the concept of gamified learning, affect the early stages of children's development. Active learning not only contributes to motivation but to retention as well.(1) On the basis of the MI theory, combined with Piaget's theory of children's cognitive development, the requirement-behavior-function-emotion structure for the design of children's toys has been proposed.(3) MI theory can also be applied to understand how children develop multiple intelligences in building block and table games and to promote the growth of their creativity, especially in aspects such as language intelligence, mathematical intelligence, and spatial intelligence.(22) Puzzles, building blocks, and construction toys can also improve imagination and spatial intelligence among the multiple intelligences.(2)

2.4 Toddler toy design theory

In the early cognitive development of children, the malleability of spatial skills is particularly important. These skills can be developed and enhanced through the use of appropriate methods and tools. Incorporating spatial skills into the development of science, technology, engineering, arts, and mathematics (STEAM) helps cultivate children's comprehensive abilities. In addition to nurturing the physical aspects of spatial cognition, construction toys also provide opportunities for spatial language, gestures, and narrative development in the interactions between children and their caregivers. These interactions are crucial for the development of spatial skills in both children and their caregivers.(23)

The design elements of building block toys must be based on the developmental characteristics of young children to promote their play and creativity. Childcare facility educators believe that the types of toys that most pique children's interest are as follows, in order: (1) building blocks, (2) pretend play, (3) puzzles, (4) snowflakes, (5) LEGO, and (6) clay.(24) The class of building block toys includes three of these items. Educators have also identified six essential elements that children's toys should possess: (1) safety, (2) educational value, (3) the ability to stimulate creativity, (4) age appropriateness, (5) alignment with children's interests, and (6) durability.[24] Educational toys during childhood can influence the development of various skills. It is crucial to choose age-appropriate educational toys to ensure that the toy's design effectively fulfills its role.[6] The color, form, and shape of toys significantly affect the preferences of masculine and feminine individuals for different toys.[6]

Smart building blocks are an educational toy that teaches STEAM concepts by assembling electronic components. At the same time, it stimulates children's creativity and problem-solving skills. These building block modules include sensors, LED lights, motors, microcontrollers, and more, which can be used to create electronic works with functional features, such as electronic toys and educational tools. These educational tools combine elements of education and technology, and encourage children to develop and learn through interactive learning. The technical availability of smart toys can be categorized into four main types: (1) tangible features, (2) augmented reality features, (3) IoT features, and (4) sensor-equipped features.[4] To improve the effect of early intervention on the cognitive learning of autistic children and overcome the limited focus, lack of interest to small children, and other problems in traditional cognitive learning, an interactive cognitive training tool including LED display technology, voice recognition technology, and infrared positioning technology has been developed for cognitive learning of the characteristics of color for autistic children.[5] Most recommendations suggest organized educational activities and a mix of free play, whether or not the toy integrates technological applications. Regardless of whether toys incorporate technology, the essence of toys and their technological applications (smart toys) is, fundamentally, fun.[4] An important question is whether smart toys can help children play and/or learn, engage socially, and/or interact with their surrounding environment, which would assist children in understanding the world around them.[4] Unfortunately, traditional toys might not achieve this goal.

2.5 Touch stimulates the senses of young children

Touch has become an important means to promote growth and development. Touch plays a crucial role in the sensory development of young children during their developmental stages.[25] Starting from infancy, it is essential to provide tactile stimulation to enhance sensory experiences and foster positive interactions between parents and infants.[26] The physical and sensory environment in early childhood education significantly impacts children's social and emotional development. Therefore, creating a conducive sensory environment holds considerable importance in early childhood development.[27] Common toy shapes and materials have proven to be effective in treating sensory sensitivity disorders.[28] Tactile perception is exhibited positively in neurotypical children across various aspects, including reaction time, amplitude discrimination (sequential and simultaneous), and temporal discrimination (temporal order judgment and duration discrimination). Additionally, children with autism demonstrated higher thresholds in amplitude discrimination and temporal order judgment than neurotypical children.[29]

3. Methodologies for Cross-domain Integration Design of Smart Building Blocks

In terms of design practice, we incorporate various methodologies in this research, including semi-structured interviews, questionnaires, observation methods, usability evaluation, and educational effectiveness evaluation. These methods have been applied in toy design.[3,30] For the development and design of smart building blocks, we follow the ten steps of the requirement-behavior-function-emotion structure.[3] Semi-structured interviews are employed to gather user experiences and opinions regarding the building blocks, providing valuable insights for designers. Observation methods are used to observe children's behavior while playing with the blocks, comparing it with the desired behavior outlined in the study to assess the feasibility of the design. Questionnaire surveys are conducted twice in this study, once to assess consumer preferences for the blocks and another time to evaluate usability and educational effectiveness from the perspectives of educators and parents.

In this study, the requirement-behavior-function-emotion structure was adopted, along with semi-structured interviews, questionnaires, and observation methods, followed by a usability test to collect feedback and identify areas requiring future improvements. The research approach outlined in this article serves as a reference and guidance for the design of future smart children's toys. Figure 1 below illustrates the study's flowchart.

3.1 Survey and evaluation of market-related products

Prior to conducting user interviews, data on popular Taiwanese market products were collected and their variations were analyzed, as shown in Table 1. The latter two lack electronic components, while the first two products are expensive, resulting in a substantial 8–40-fold

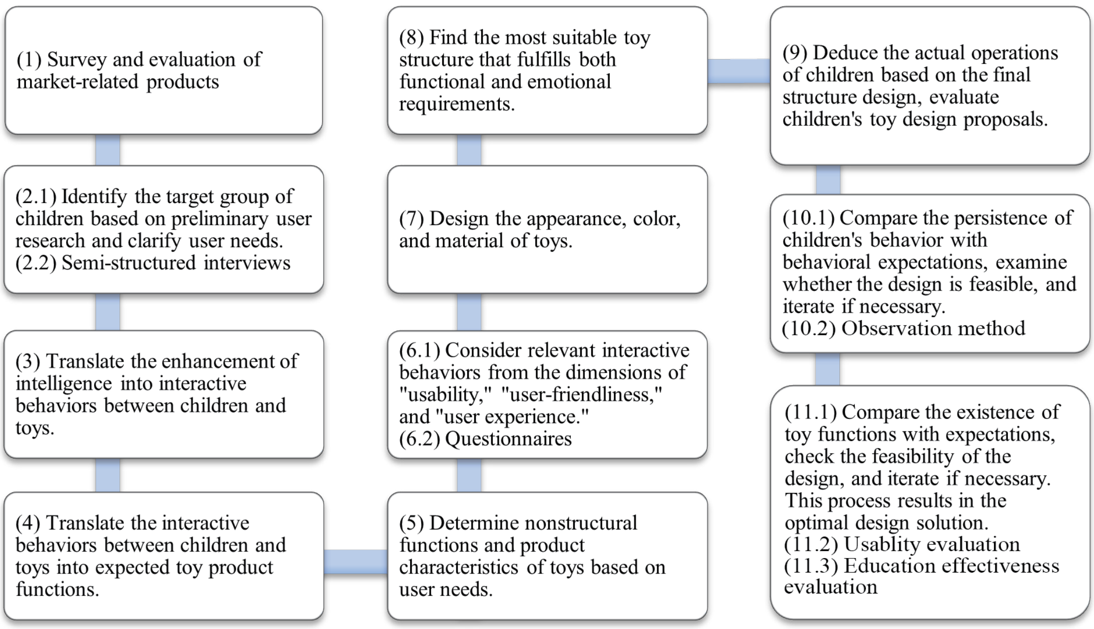
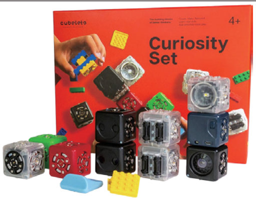


Fig. 1. (Color online) Flowchart of smart building blocks design.

Table 1
(Color online) Evaluation of market-related products.

Product name	Robotics Prodigy	Cubelets Curiosity Set	LEGO	STEAM Innovative Intelligence Development Toys
Image of product				
Company	Robo Wunderkind	Modular Robotics	The Lego Group	Yuedu Famous Publishing Co., Ltd.
Materials	• ABS plastic • Electronic parts	• ABS plastic • Electronic parts	• ABS plastic	• ABS plastic
Price	250 USD	399 USD	10 USD and above	30 USD and above
Feature	• The app to control the robot instantly • Proximity sensor • Motion detectors • Light sensors • Can be programmed	• The magnetic surfaces of cubes make them easy to interlock and pull apart • Each cube has a special function • Cubelets Curiosity Set	• Exquisitely designed and versatile in assembly • Features a variety of themed building blocks	• Various mechanical combination styles • Good value • The manual is very detailed
Source	https://www.robowunderkind.com/	https://modrobotics.com/	https://www.lego.com/en-us	https://www.zeczec.com/projects/steam-237-60

price difference. The high cost of smart building blocks limits their accessibility, and they are mainly used for educational purposes to teach robotics and programming. Smart building blocks offer electronic components but also maintains a range of popular themed plastic building blocks alongside smart building blocks. Therefore, in this study, we suggest that by compromising some smart block features, designing more affordable options can serve as an entry point for advanced users.

Not only the four mentioned brands but also collected data on safety regulations for toys are used to ensure that the designed building blocks with sensors comply with safety standards. Regarding material and tactile considerations, the materials of brands on the market are generally categorized into the following five types.

(1) Soft Blocks: These blocks are made of soft materials and are suitable for infants and toddlers aged 0 and above. Soft blocks have a design with rounded edges, ensuring safety. They often have fabric surfaces, providing better skin contact for infants.

(2) Wooden Blocks: Made from nontoxic natural wood, these blocks are sturdy and suitable for children aged 3 and above. They are durable, offer creative possibilities, and have a textured surface for tactile feedback and ease of handling by kids.

(3) Plastic Blocks: Plastic blocks are made of plastic with nontoxic certification. Large-sized plastic blocks are suitable for children aged 1 and above, offering extensive creative possibilities.

(4) Magnetic Blocks: Magnetic blocks are typically made by combining magnets with wooden or plastic blocks. Because of the small size of magnets in the magnetic blocks, they are suitable

for slightly older children. The invisible magnetic force adds to the appeal of magnetic blocks.

(5) Smart Blocks: These blocks combine chips, sensors, motors, and technological components with plastic. Currently, wooden smart blocks are unavailable. They perform intelligent actions not achievable by the other four types but are relatively costly owing to the inclusion of technological components and programming. They are commonly used in educational settings, but private courses can incur high costs, limiting their popularity compared with the other four types.

3.2 Results of questionnaire

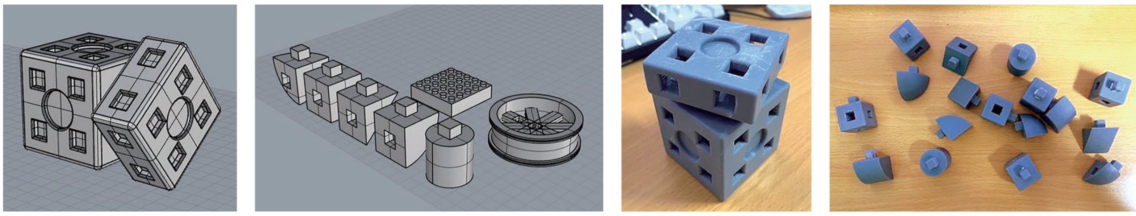
A total of 144 respondents were interviewed, ranging in age from 20 to 50 years old. Among them, 87% of the respondents had experience in buying and selling educational toys for children. Table 2 below shows the product quality that consumers prioritize, with the questionnaire options set to "multiple selections allowed", except for the last question. The table presents the top four rankings. In terms of purchasing preferences, the top four results are inspirational, safety, creativity, and educational. Regarding toy characteristics, the top four results are promotes hand-eye coordination, safety, cultivates independent thinking, and inspirational. In terms of design preferences, the top four results are thematically relevant, colorful, price, and rich in design. In terms of pricing, the most acceptable price range is 500–1000 NTD.

3.3 Form design of smart building blocks

To implement the design, in this stage, the appearance of the building blocks is visualized. Using 3D software, the specific design of the appearance is created first, and the rationality of the assembly between the blocks is checked. The positioning of sensors required for the blocks also needs to be considered. Then, four toy designers are invited for expert discussions to bring the block design closer to the level of mass production. The three-dimensional model design of sensor blocks is shown in Figs. 2(a) and 2(b). The core body of the blocks has rotating, extending, and swinging functions, providing a pattern of repetitive movement when the blocks are connected. There are six basic block styles, and thus could allow for greater diversity in

Table 2
Evaluation of customer's preferences of market-related products.

1. Purchasing preferences	Inspirational (91.7%)	Safety (79.2%)	Creativity (75.0%)	Educational (75.0%)
2. Toy characteristics	Promotes hand-eye coordination (91.7%)	Safety (87.5%)	Cultivates independent thinking (79.2%)	Inspirational (75.0%)
3. Design preferences	Thematically relevant (75.0%)	Colorful (75.0%)	Price (50.0%)	Rich in design (41.7%)
4. Pricing preferences (NTD)	500–1000 (45.8%)	1000–2000 (25.0%)	100–500 (20.8%)	2000 and above (8.3%)



(a) (b) (c) (d)

Fig. 2. (Color online) The demonstrations of smart building blocks design. (a) and (b) show 3D model designs of blocks, (c) and (d) show the physical prototypes of the 3D-printed blocks.

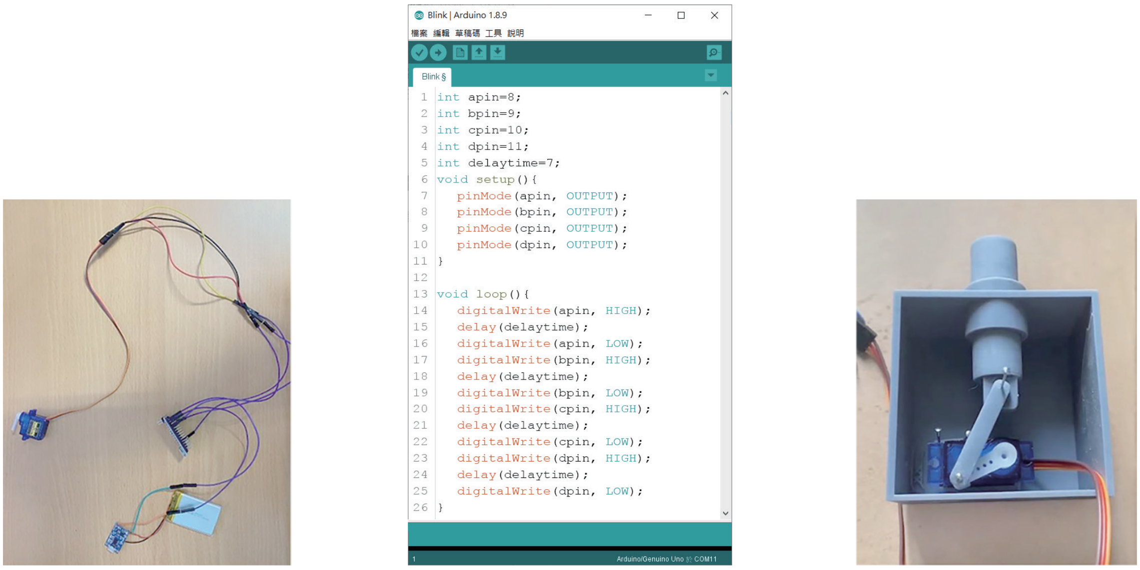
assembled objects.. Whether the core body or basic blocks, they can be further developed into a series of products for different themes in the future.

After confirming the 3D model's appearance and the mechanical design of the building blocks, the next step is to create physical prototypes of the blocks through photopolymerization 3D printing. This facilitates subsequent testing and assembly. The advantage of physical testing of the blocks is the ability to perform real-world assembly exercises, preventing any oversights. The physical prototypes of the 3D-printed blocks are shown in Figs. 2(c) and 2(d).

3.4 Experiments with cross-domain integration design

In the realm of interdisciplinary integrated design, the initial phase entails the assembly of multifarious components including sensors, motors, circuit boards, and microbatteries. Throughout the assembly and testing process, extended wire lengths were deliberately utilized for convenience, as depicted in Fig. 3(a), which showcases the sensor group assembly. Following this phase, programming was executed to orchestrate the sensor group's intended functionality, as shown in Fig. 3(b). Subsequent to the successful validation of the programming test, amalgamation of electronic components and building blocks ensued. Any surplus wire length was pruned to ensure a snug fit within the structural slots of the core build module. A visual depiction of the electronic component assembly situated at the designated locus for the sensor block mechanism is presented in Fig. 3(c). The battery selection was prioritized on the basis of cost-effectiveness and compactness, thereby refraining from utilizing rechargeable batteries. Nonetheless, with ongoing technological advancements, the potential inclusion of smaller rechargeable batteries remains a viable prospect for future consideration. The forthcoming iterations of sensor modules will be meticulously designed to accommodate prospective updates in product advancement.

The assemblage of blocks integrated with electronic components underwent rigorous testing to validate the cohesive functionality of the assembled thematic structure. The outcomes of this specialized assembly test are graphically depicted in Fig. 4. Deliberate finalization encompassed the external and mechanical design aspects alongside the meticulous arrangement of electronic components within the sensor blocks. The incorporation of three fundamental motion modes—rotation, swing, and telescoping—reflects the innate simplicity ingrained in natural motion.



(a) (b) (c)

Fig. 3. (Color online) Sensor block's (a) sensor assembly photo, (b) programming screenshot, and (c) photo of installed electronic components.

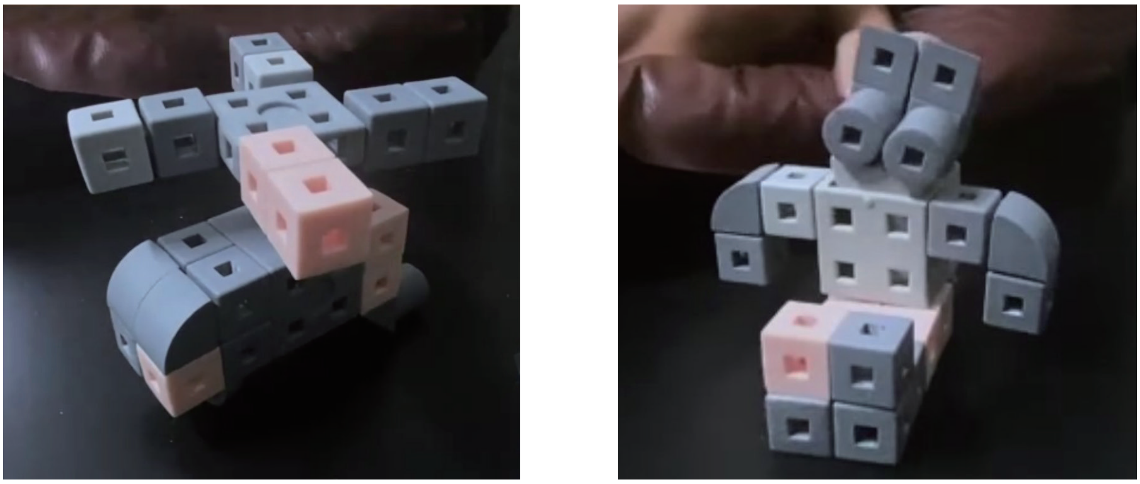


Fig. 4. (Color online) Photos of the thematic assembly test of the sensor blocks.

Leveraging these fundamental modes, the electronic building block toys are conceptualized to harness the blocks' embedded latches to facilitate seamless connectivity and the subsequent propulsion driven by electronic components. This design allows users to witness the dynamic interplay among the blocks, initiating motion and interactions. Notably, the product offers users an intuitive experience, which provides immediate feedback and a sense of achievement without the necessity for electronic or engineering proficiency or programming prowess.

4. Experimental Results

In this study, three different groups of building blocks for experimentation were formed: the traditional group, the control group, and the experimental group.

(1) Traditional Group: Emphasis is solely on intelligence, and traditional knowledge transmission methods are used without the use of building blocks in teaching or for entertainment at home.

(2) Control Group: Conventional plastic building blocks are used for both teaching and home entertainment. During the experiment, the building blocks developed in this study but without electronic components are utilized.

(3) Experimental Group: Both smart building blocks and regular plastic building blocks are employed for teaching and home entertainment. During the experiment, the smart building blocks developed in this study, which included electronic components, are used.

In accordance with toy safety regulations, the building blocks developed in this study are not suitable for infants and toddlers under the age of 3. Considering the pricing constraints gleaned from questionnaire results, the smart building blocks are priced in the range of 500–1000 NTD. These smart building blocks incorporate electronic components but do not provide users with the ability to write programs to control and operate the building blocks. Therefore, the target user group is children aged 5–10. Considering the difficulty of experiment questionnaire responses for this age group, respondents were changed to educational staff caring for children and parents.

A total of 11 educational staff personnel and 27 parents were invited to fill out building block evaluation questionnaires, including a usability evaluation and an educational effectiveness evaluation. The data analysis was conducted separately for the assessments of educators and parents to understand whether there were differences in product evaluations depending on respondents' educational perspectives.

In the usability assessment survey, five questions were incorporated. The evaluation profiles of 11 educators are detailed in Table 3. Cronbach's alpha calculated through data reliability analysis yielded a coefficient of 0.83, signifying a high coherence and reliability of the questionnaire. On the whole, the mean score of the experimental group surpassed that of the

Table 3
Average values of usability evaluation by educational staff.

Questions	Groups		
	Traditional group	Control group	Experimental group
u1. Do you like the appearance and design features of this building block?	2.8	3.6	4.3
u2. Do you like the interactivity and playability of this building block?	2.9	3.7	4.5
u3. Do you consider this building block to be safe and durable?	3.1	3.8	4.2
u4. Do you think this building block is suitable for children aged 5–10?	3.0	3.5	4.1
u5. Overall, are you satisfied with this building block?	2.9	3.7	4.4
Average value of each group	2.9	3.7	4.3

control group, while the control group's mean score outperformed that of the traditional group. Specifically, the experimental group exhibited values equal to or surpassing the group mean in aspects such as (u2) interactivity and playability of the blocks, (u1) appearance and design features of the blocks, and (u5) satisfaction.

The usability assessment data from 27 parents, as presented in Table 4, underwent reliability analysis, yielding a Cronbach's alpha coefficient of 0.87, signifying the high coherence and reliability of the questionnaire. To summarize, the mean scores of individual parameters within the experimental group surpassed those of the control group, which, in turn, exceeded those of the traditional group. In particular, three metrics within the experimental group, specifically, (u2) interactivity and playfulness of the building blocks, (u5) satisfaction, and (u1) appearance and design features of the building blocks, either equaled or exceeded the group mean.

The MI theory served as the framework for the educational effectiveness evaluation questionnaire. It comprised eight questions, omitting musical intelligence while introducing an overall evaluation query. The results outlined in Table 5 show the mean appraisal by 11 educational staff members, yielding a Cronbach's alpha coefficient of 0.84 following reliability analysis, signifying the high coherence and reliability of the questionnaire. On the whole, the mean values for each parameter within the experimental group surpassed those of the control group, which, in turn, exceeded those of the traditional group. Specifically, five parameters within the experimental group, denoted as (e3) spatial awareness, (e2) logical thinking, (e7) natural intelligence, (e8) overall educational value, and (e4) hand-eye coordination, either equaled or exceeded the group's mean.

The average educational effectiveness evaluation scores of 27 parents are tabulated in Table 6. These scores underwent rigorous reliability analysis, yielding a Cronbach's alpha coefficient of 0.86, denoting robust coherence and reliability within the questionnaire. Notably, the mean values in the experimental group surpassed those in the control group, which, in turn, surpassed those in the traditional group. Among experimental cohorts, scores for five specific domains, (e3) spatial awareness, (e2) logical thinking, (e7) natural intelligence, (e8) overall educational value, and (e4) hand-eye coordination, either equaled or exceeded the group's mean score.

Table 4
Average values of usability evaluation by parents.

Questions	Groups		
	Traditional group	Control group	Experimental group
u1. Do you like the appearance and design features of this building block?	3.0	3.8	4.5
u2. Do you like the interactivity and playability of this building block?	3.1	3.9	4.7
u3. Do you consider this building block to be safe and durable?	3.3	4.0	4.4
u4. Do you think this building block is suitable for children aged 5–10?	3.2	3.7	4.3
u5. Overall, are you satisfied with this building block?	3.1	3.9	4.6
Average value of each group	3.1	3.9	4.5

Table 5
Average value of effectiveness evaluation by educational staff.

Questions	Groups		
	Traditional group	Control group	Experimental group
e1. Do you believe this building block has educational value in language education?	2.7	3.5	4.1
e2. Do you believe this building block has educational value in logical thinking?	3.0	3.8	4.6
e3. Do you believe this building block has educational value in spatial awareness?	3.1	4.0	4.7
e4. Do you believe this building block has educational value in hand-eye coordination?	3.3	4.1	4.4
e5. Do you believe this building block has educational value in interpersonal intelligence?	2.9	3.7	4.2
e6. Do you believe this building block has educational value in intrinsic intelligence?	2.8	3.6	4.3
e7. Do you believe this building block has educational value in natural intelligence?	2.6	3.4	4.5
e8. Overall, do you believe this building block has educational value?	2.9	3.8	4.5
Average value of each group	2.9	3.7	4.4

Table 6
Average value of educational effectiveness evaluation by parents.

Questions	Groups		
	Traditional group	Control group	Experimental group
e1. Do you believe this building block has educational value in language education?	2.9	3.7	4.3
e2. Do you believe this building block has educational value in logical thinking?	3.2	4.0	4.8
e3. Do you believe this building block has educational value in spatial awareness?	3.3	4.2	4.9
e4. Do you believe this building block has educational value in hand-eye coordination?	3.5	4.3	4.6
e5. Do you believe this building block has educational value in interpersonal intelligence?	3.1	3.9	4.4
e6. Do you believe this building block has educational value in intrinsic intelligence?	3.0	3.8	4.5
e7. Do you believe this building block has educational value in natural intelligence?	2.8	3.6	4.7
e8. Overall, do you believe this building block has educational value?	3.1	4.0	4.7
Average value of each group	3.1	3.9	4.6

5. Discussion

5.1 Discussion of usability evaluation

In the usability evaluation, smart building blocks were assessed regarding educational and entertainment purposes by educational staff and parents. Three groups were involved: traditional methods, general plastic building blocks, and smart building blocks with electronic components. Notably, both educational staff (0.83) and parents (0.87) showed consistent and dependable results with Cronbach's alpha.

(1) Educational Staff Preference: Smart building blocks received high praise from educational staff, with significant ratings for appearance, interactivity, safety, suitability for ages 5–10, and overall satisfaction. These findings highlight the value of smart building blocks in education and entertainment.

(2) Parental Favorability: Parents also favored smart building blocks, indicating their preference for appearance, interactivity, safety, suitability for children, and overall satisfaction. These results demonstrate the acceptance of smart building blocks as educational and entertainment tools.

The usability evaluation underscores the advantages of smart building blocks with electronic components in terms of usability, appeal, and educational value. Both educational staff and parents expressed a strong preference for these blocks, making them a promising tool for enhancing children's learning and entertainment experiences. Further research is needed to fully harness their potential in education and child development.

5.2 Discussion of educational effectiveness evaluation

In the educational effectiveness evaluation, high Cronbach's alpha values (0.84 for educational staff and 0.86 for parents) validate the consistency and reliability of the evaluations.

(1) Educational Staff Preference: Educational staff consistently preferred smart building blocks over traditional methods, showcasing the effectiveness of smart building blocks in enhancing language education, logical thinking, spatial awareness, hand-eye coordination, and more.

(2) Parental Favorability: Parents preferences mirrored those of educational staff, indicating that they recognized the educational value of smart building blocks in enhancing language skills, logical thinking, spatial awareness, and more.

Both educational staff and parents acknowledge the value of smart building blocks in promoting various cognitive skills and overall educational development. Smart building blocks, with electronic components, offer a promising avenue for enhancing children's educational experiences. Further exploration and development in this area are encouraged to maximize the benefits for young learners.

6. Conclusions

Smart building blocks, equipped with electronic components, were subjected to rigorous usability and educational effectiveness evaluations by educational staff and parents. The findings from both evaluations indicate robust consistency and reliability in endorsing these blocks as potent tools for educational enhancement and entertainment. Notably, both educational staff and parents exhibited a strong inclination towards smart building blocks, signifying their multifaceted value in fostering children's learning experiences. In the usability assessment, smart building blocks garnered high praise for their aesthetic appeal, interactivity, safety features, and suitability for children, fostering an encompassing satisfaction among both educators and parents. The significant preference shown by educational staff and parents emphasizes the educational and entertainment value of these blocks, warranting further exploration to harness their full potential in childhood education and development. The educational effectiveness evaluation further substantiated the positive impact of smart building blocks, as both educational staff and parents acknowledged their role in enhancing language skills, logical thinking, spatial awareness, and other cognitive abilities. These findings emphasize the significant potential of smart building blocks, underpinning their promising effects in augmenting educational experiences and cognitive development in young learners. The results of these evaluations collectively highlight the promising future of smart building blocks in early childhood education, advocating for their integration and further development to maximize their benefits for children's holistic development and learning experiences.

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