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Research on the Integration of Toys and Electronic Devices and Its Development Trends

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Abstract:

With the maturation of VR/AR technologies, advancements in 3D printing, and the practical application of AI, an increasing number of everyday objects are becoming intelligent. Meanwhile, the traditional toy market is nearing saturation, and parents' educational perspectives are evolving. This raises the important question of whether digital technologies can provide solutions to integrate new technologies into toys, thereby enhancing their educational value, interactivity, and playability. Toy design has always been a sensitive topic; many new technologies, despite their maturity, often remain at a distance from the toy industry. This article aims to analyze the applicability of new technologies in the direction of toy design. Using literature review and case study methods, this paper examines the historical development of toys and analyzes both positive and negative cases of integrating new technologies with toys. The findings reveal that the toy sector is often one of the last areas to be impacted by the proliferation of new technologies. For new technologies to be applied to toys, they must undergo thorough evaluation and consideration from multiple perspectives. Subsequently, the paper analyzes the applicability of VR/AR and 3D printing technologies in toy design, summarizing their advantages and existing challenges within this field. Finally, the article offers insights into the future development of toys.

Keywords: Toy Design; VR technology; AR technology; 3D printing technology; smart toys.

1. Introduction

This study focuses on the current saturation of the traditional toy market and the demand for innovative toys among consumers. It is particularly significant in exploring the integration of new technologies within the toy industry and how these technologies can enhance the interactivity and educational value of toys. The research primarily examines the historical development of toys and specific toy cases, employing

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a literature review method to gather and analyze relevant materials and studies. This method is advantageous as it effectively analyzes existing attempts to combine technology with toys, allowing for the formulation of pertinent conclusions that support the research process. The ultimate objective of this study is to summarize the relationship between new technologies and toy development, analyze the advantages of emerging technologies in the field of toy design, and identify the challenges and barriers to their integration. Furthermore, the study aims to provide recommendations and insights for the future development of toys.

With advancements in technology, the evolution of future toy design will inevitably be closely linked to cutting-edge innovations, aiming for higher levels of intelligence, a stronger technological atmosphere, and richer experiential encounters. This study aims to understand the current development status of the global smart toy market by examining the historical integration of toys with contemporary technologies, focusing on the timing, methods, impacts, and analyzing specific toy cases. It will discuss how high-tech innovations can be integrated with toys today, potential issues and barriers, and assess their significance. Through the collection and analysis of specific case studies, this research will forecast future developmental trends, providing a foundation for the design of smart toys moving forward.

2. Background

Childhood is a critical phase in an individual‘s developmental journey, and its importance extends beyond rapid physical growth to encompass cognitive development, emotional nurturing, and the early formation of social skills. During this pivotal period, toys play an irreplaceable role; they are not only intimate companions in children‘s daily lives but also essential tools for exploring the world and stimulating imagination and creativity. As global educational philosophies continue to advance and refine, there is an increasing recognition of the core value of toys in children‘s growth, leading to unprecedented attention to toy design and its future development.

In recent years, the rise of the experience economy has catalyzed a profound transformation in the field of toy design. Against this backdrop, integrating toys with advanced technologies and interactive design concepts has emerged as a significant trend in the evolution of toy design. However, there has been limited practical application of these technologies in specific toy designs. Therefore, researching how to better combine toy design with cutting-edge technologies holds substantial importance.

2.1 Current State of the Toy Industry

2.1.1 Saturation of the traditional toy market

Currently, mainstream children‘s toys primarily consist of traditional types such as puzzles and musical toys, characterized by their relatively simple structures. These toys often lack variety and novelty, offering limited interactive experiences that fail to sustain children‘s interest over time. As a result, they fall short of the expectations that parents have for educational toys. With the advancement of educational philosophies, the criteria for selecting toys have gradually become more stringent, leading to significant challenges for the traditional toy market, which is experiencing a gradual decline in market share.

According to data from the Japan Toy Association, the Japanese toy market contracted by 2.5% in 2013 compared to the previous year, shrinking by 673 billion yen. In contrast, the smart toy market grew by 7.4%, reaching 6.3 billion yen [1]. Similarly, negative export growth for traditional toy products has been observed in major toy-producing countries in Asia, indicating that the traditional toy market is nearing saturation.

2.1.2 Current state of the global toy industry

The global toy industry is undergoing a significant transformation, with the most notable trend being the continuous increase in market share for high-tech electronic toys, while the traditional toy market is gradually contracting. As technological advancements and changes in consumer preferences reshape the landscape, toy design and production are increasingly focusing on innovation and the integration of technology. Smart toys and electronic tech toys have emerged as new favorites in the market.

“According to a survey conducted by the Toy Association in the United States, the internal structure of the global toy market has undergone significant changes in recent years. The market share of traditional toys is declining, while the share of high-tech electronic toys has been rising year after year [2].” This trend reflects consumers‘ heightened demand for interactivity, educational value, and technological sophistication in toys. Although traditional toys still occupy a portion of the market, they increasingly struggle to meet modern children‘s needs for novel experiences and knowledge exploration. In contrast, high-tech electronic toys provide children with richer, more diverse, and personalized play experiences by incorporating the latest technologies, such as artificial intelligence and virtual reality.

As a result, the global toy industry is accelerating its transition toward high-tech and high-value-added products to adapt to changing market demands.

2.2 Upcoming Transformations in the Toy Industry

2.2.1 Application of new technologies

As personalization, portability, and networking technologies become increasingly integrated into learners‘ daily lives, exploring how to effectively incorporate these emerging technologies into children‘s lives or toy design

has become a critical topic. The rapid advancement of technology—particularly the rise of wireless technology, handheld devices, and VR/AR alongside 3D printing—has garnered significant interest not only from hobbyists but also among children. Many toy manufacturers have begun to experiment with the integration of new technologies into toys. Although such toys have yet to dominate the market, there are already several successful examples that have emerged.

2.2.2 Advantages of applying new technologies in products

The integration of technologies such as Virtual Reality (VR) and Augmented Reality (AR) significantly enhances the interactive experience of toys. VR technology creates immersive virtual environments, allowing users to engage deeply in games or experiences. This enables children to interact with objects in a virtual world, which not only increases the playfulness of toys but also promotes social interaction and cognitive development among children. Preliminary research indicates that 30 minutes of daily VR usage does not adversely affect the vision of children aged 10 to 12, suggesting that VR devices can be used safely in educational contexts [3].

AR technology adds a new dimension and layer to toys by overlaying virtual elements onto the real world, making play more diverse and engaging. AR toys can illustrate the internal structure and working principles of the toy through virtual elements, facilitating children‘s understanding and learning of related concepts. This encourages interactive exploration and stimulates their curiosity and creativity regarding nature and various fields of knowledge.

Additionally, 3D printing technology allows users to design and print unique toys tailored to their preferences and needs, satisfying children‘s desire for personalization. This technology provides ample opportunities for children to showcase their creative abilities and inspires their innovation. Moreover, the application of 3D printing in the toy industry aligns with environmental and sustainability trends, as many 3D printing materials are biodegradable, contributing to the sustainable development of the toy sector.

Furthermore, surveys indicate that innovative smart toys tend to be more popular. Research confirms that consumer innovativeness correlates positively with the willingness to pay through perceived product innovativeness [4]. As a result, intelligent toys can significantly enhance consumers‘ purchasing intentions.

2.2.3 Growing market share of smart toys and expanding consumer base

With the advancement of the information age in electronic technology, the integration of technology into traditional toy design has become a significant highlight in the toy market. Observably, new brands and products in this category are increasingly appearing. According to statistical data, the current global smart toy market is valued at $500 million, and it is projected to reach approximately $69.9325 billion by 2026 (Transparency Market Research, 2018). It is believed that IoToys and STEM (Science, Technology, Engineering, and Mathematics) toys are key components driving the market‘s growth. Enhancing the interaction between smart toys and users can strengthen their dominant position in the market. Moreover, improving children‘s STEM skills through the use of smart toys can motivate parents to purchase these toys for their children [5]. Therefore, the market for smart toys, which represents a significant trend in the global toy industry, is vast and promising.

3. Analysis of Historical Integration Points Between Toys and Emerging Technologies

The origin of toys can be traced back to ancient times, initially comprising simple objects made from natural materials such as sand, stones, and twigs. As human civilization progressed, toys gradually evolved into items that utilized contemporary technologies, with their materials and techniques closely linked to the craftsmanship and manufacturing capabilities of the era.

In comparison to other products such as production tools and weapons, toys have historically held a lesser significance. Their social status influences the timing of the application of emerging technologies or new materials within the realm of toys. During the feudal era, new technologies were primarily first applied to rituals and production. Consequently, the incorporation of cutting-edge technologies into toys often lagged behind their initial inventions. For instance, the art of clay modeling from China‘s Neolithic period dates back to its origins, primarily serving ritualistic purposes with little use as toys. It was not until the Han Dynasty that a significant number of clay toys emerged. Similarly, advancements in metal casting and glass-making techniques were first applied to the production of agricultural tools, weapons, and ceremonial items, only later finding application in the creation of toys once these processes matured.

3.1 Electricity Incorporated into Toy Design

The history of electric toys dates back to the early 19th century, when the exploration of electrical technology began. The earliest electric toys were produced by several manufacturers in Europe, notably Markus of Germany, who created an electric toy called the „Wireless Engine“ in 1880, marking it as the first electric toy in history. Shortly thereafter, the A.C. Gilbert Company in the United States launched the „Railroad Kingdom“ electric train set, which became the first mass-produced electric toy. This development ushered in a new era of integration between

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toy design and technology.

3.2 Displays Integrated into Toys

The use of displays in toys dates back to the 1990s, when touch screen technology began to emerge in high-end personal digital assistants (PDAs). In 2004, Nintendo launched the Nintendo DS (NDS), which was the first portable gaming console to widely implement touch screen technology for game control. The success of the NDS rapidly popularized touch screen technology, bringing it into the mainstream. Additionally, the application of display technology in educational toys has been increasing, exemplified by LEGO's introduction of the Builder app in 2019, which aids players in mastering LEGO building techniques more efficiently. LEGO also launched the online social platform, Lego Life, providing a social network for young users.

Despite the popularity of toys and devices equipped with screens, their potential harms should not be overlooked. These devices may lead to physical issues such as vision decline and neck pain, as well as increase the risk of myopia and dry eye conditions in children. Psychologically, excessive screen time can contribute to or exacerbate feelings of depression and anxiety among children [6]. Therefore, it is crucial to monitor children's screen usage time and implement effective strategies to guide them toward reasonable use of screens.

3.3 Counterexamples of New Technology Applications in Toys

In 1945, the successful detonation of an atomic bomb in the United States marked a milestone event that significantly heightened global interest and attention toward nuclear technology. The explosive power of the bomb, coupled with the scientific principles underlying nuclear science, sparked public curiosity and a desire for exploration regarding atomic energy. Toy manufacturers recognized this opportunity and began to experiment with integrating elements of nuclear science into toy design.

One notable example is the "Gilbert U-238 Atomic Energy Lab," produced by the Gilbert Toy Company in the United States. This toy set included genuine samples of uranium ore, as well as other radioactive elements such as lead-210 and polonium-210. Additionally, the toy came equipped with scientific instruments, including a cloud chamber for observing alpha particles. However, due to the inclusion of radioactive elements that posed potential harm to human health—specifically, the risk of damaging organs such as the liver, kidneys, and heart—the toy faced widespread criticism shortly after its release. Ultimately, it was forced off the market. Despite Gilbert's claims that the design aimed to inspire children's enjoyment of scientific exploration, the inherent dangers of the toy could not be overlooked, leading to its classification by the media as one of the "Top Ten Most Dangerous Toys."

3.4 Section Summary

Considering practical needs and urgency, as well as economic benefits and technological maturity, new technologies or materials often require rigorous testing and validation to ensure their reliability and safety. This process can be time-consuming, and only after achieving a certain level of technological maturity is consideration given to applying these innovations in consumer products such as toys. The timeline for this technological readiness can vary significantly, ranging from a few months to several decades, depending on the type of technology and various other factors. However, before any technology is integrated into toys, thorough assessments of safety, usability, and potential negative effects must be conducted. History has shown that some toy manufacturers, in their haste to capitalize on economic gains and marketing hype, have rushed products to market, resulting in irreversible harm to child users. Therefore, the application of any technology in toys should be approached with careful research and evaluation.

4. Analysis of Modern Cases of Integrating New Technologies with Toys

4.1 Specific Toy Cases

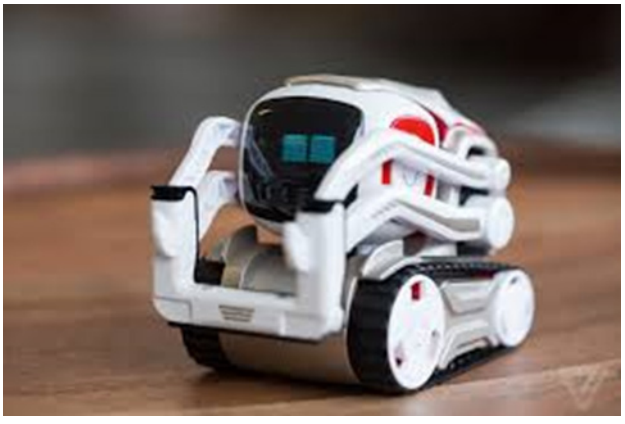

Fig. 1 Cozmo Robot

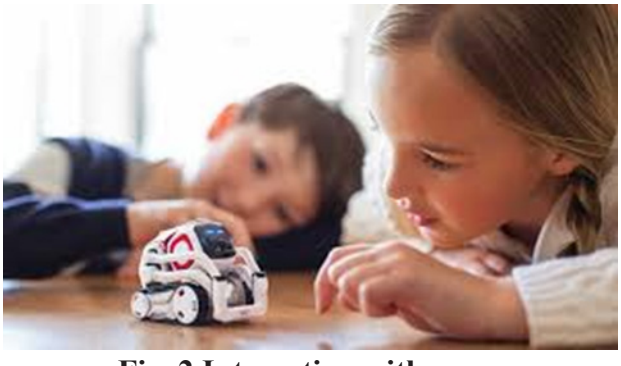

Fig. 2 Interacting with users

Cozmo, an intelligent toy robot developed by Anki, was released in 2016. It features an OLED display that showcases a wide range of facial expressions, while its eyes, which change shape according to its mood, which can be seen in figures 1 and 2, enhance the liveliness of its interactions with users. Cozmo is equipped with an AI system that enables natural social interactions. Additionally, it includes a front-facing 30FPS VGA camera and facial recognition software, allowing it to see and remember users' faces and respond to specific commands and emotions. Its wheels, movable arms, and built-in motors and gears enable Cozmo to perform various actions, resulting in over 1,000 different reactions. Cozmo also demonstrates learning capabilities, adapting and altering its behavior based on user interactions; for example, it may display an angry expression and „bang the table" when it loses a game. Users can engage in interactive games with Cozmo through a dedicated app, enjoying a variety of gaming options. Moreover, Cozmo supports programming functionalities, which not only sparks teenagers' interest in coding but also encourages them to learn advanced programming languages such as Python and C++." The results in Section IV show good alignment between the intended and perceived Cozmo emotions, and the findings also demonstrate that the emotional display of Cozmo influences other ways in which the robot is perceived by users." [7]. Cozmo Robot has developed its own response system, capable of influencing the emotions of users who interact with it, thereby allowing users to experience the joy and surprises brought by artificial intelligence.

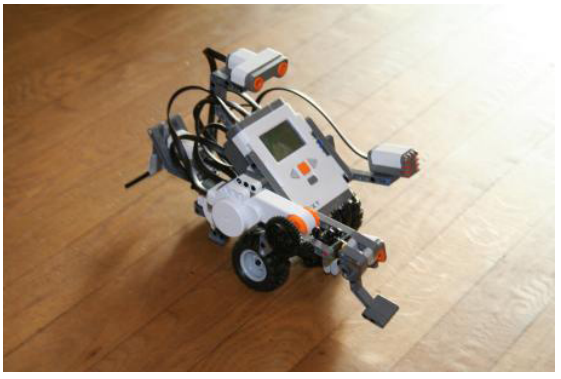

Fig. 3 Robot built with LEGO Mindstorms

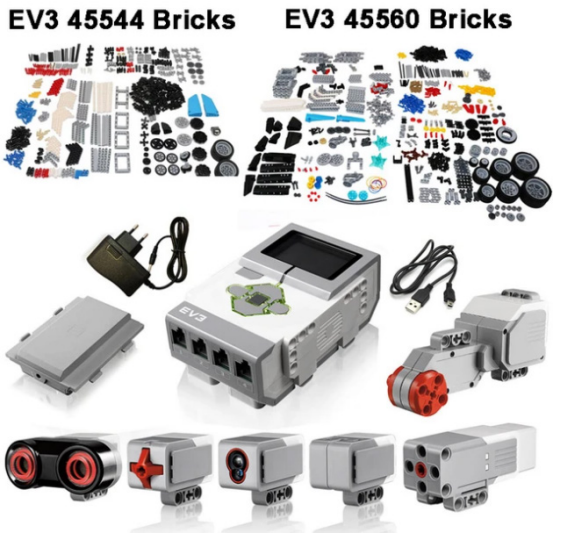

Fig. 4 Components from LEGO Mindstorms

The LEGO Mindstorms series, launched in 1998, has become a beloved brand of robotic toys among users worldwide. This series skillfully combines the flexible construction features of LEGO bricks with cutting-edge smart technology. Through an intuitive programming software—the Scratch-based LEGO® MINDSTORMS® application, which supports multiple operating systems—users can set various actions and tasks for their constructed robots(figure 3), facilitating intelligent operations. Equipped with color sensors, distance sensors, gyroscopes, accelerometers, and motors (can be seen in figure 4), the robots can perceive their environment and execute complex tasks. Users can also interact with the robots through smartphones or tablets, programming them to complete specific tasks or participate in games. The LEGO Mindstorms series serves not only as an entertaining toy but also as an educational product that promotes learning through play. In a study cited in reference, most educators expressed positive feedback regarding the use of LEGO Mindstorms EV3 as an educational tool, noting its effectiveness in stimulating children's interest in learning and creativity, fostering logical thinking and teamwork skills [8]. Additionally, it provides abundant teaching resources to support teachers and parents in guiding children's learning, thus seamlessly integrating play with education.

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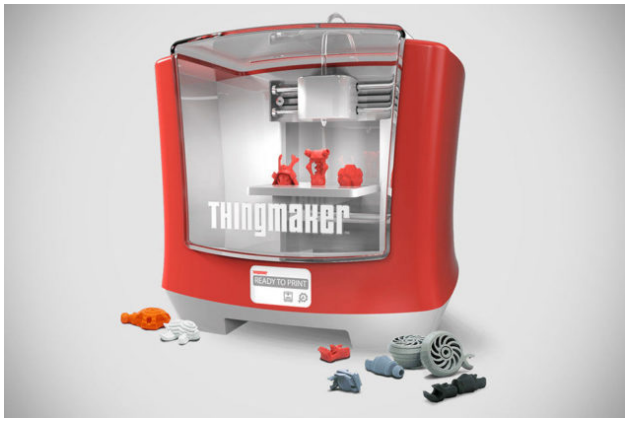

Fig. 5 ThingMaker 3D Printer

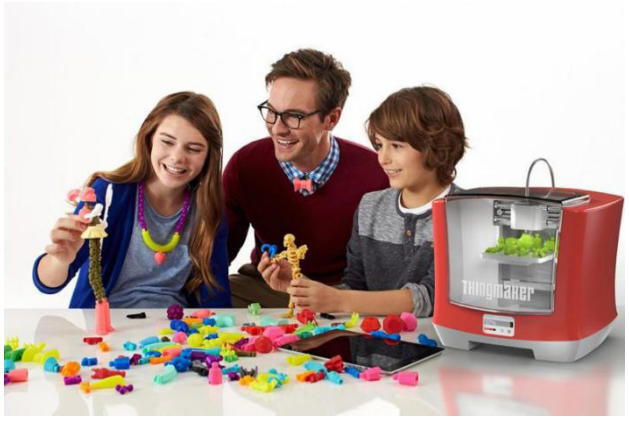

Fig. 6 Models printable by ThingMaker 3D

The ThingMaker 3D (figure 5), launched by Mattel, is an innovative toy product specifically designed for children, integrating 3D printing technology with the joys of toy creation. This printer features multiple safety mechanisms, such as an automatically locking device door during printing and a retractable print head when idle, effectively reducing the risk of accidental contact and injury to children. To enhance the user experience, Mattel collaborated with Autodesk to develop the Thingmaker Design App, which not only controls the printer but also provides a rich array of 3D modeling tools and materials. Users can easily design and print unique toy models, including rings, necklaces, scorpions, dinosaurs, and skeletons (figure 6). The ThingMaker 3D printer utilizes standard plastic filaments, such as PLA, ensuring high printing efficiency and ease of operation while posing no health risks to users.

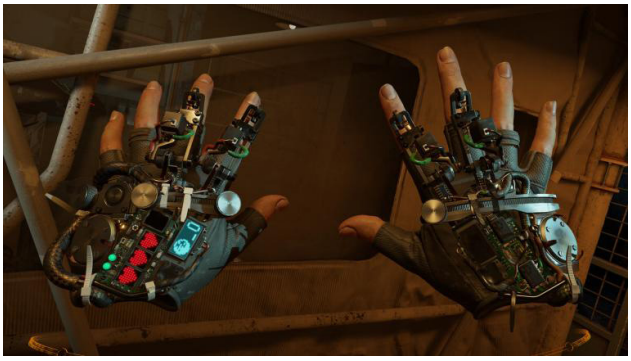

Fig. 7 High level of interaction in Half-Life: Alyx

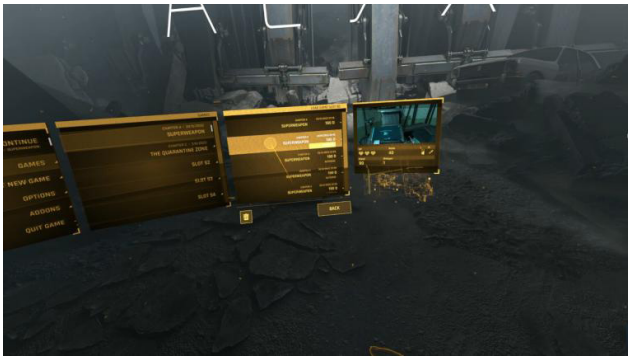

Fig. 8 High level of interaction in Half-Life: Alyx

Data indicates that the virtual reality (VR) industry generated $1.1 billion in revenue in 2020, and experts suggest that as the prices of VR systems decline, the technology will become increasingly popular in the next three to four years. „Half-Life: Alyx“ a groundbreaking title in the realm of VR gaming, immerses players in a seemingly realistic game world through the use of VR headsets. In this environment, players can move freely, explore, and engage in intricate interactions with various objects and surroundings, such as pushing aside debris to collect ammunition. This level of nuanced interaction significantly enhances the game‘s realism and enjoyment (figure 7 and 8).

The game employs an advanced physics engine that endows objects and environments with authentic physical properties, allowing players to genuinely perceive the weight of items and the feedback from collisions, further intensifying the immersive experience. Additionally, „Half-Life: Alyx“ leverages the interactive capabilities of VR devices by providing multiple interaction methods, including gestures and head movements, which contribute to a more natural and fluid gaming experience.

Moreover, the efficient environmental rendering technology creates realistic scenes and lighting effects, with meticulous attention to texture details that strive to replicate

the real world, thus offering players an immersive visual experience. The integration of artificial intelligence (AI) technology within the game results in intelligent enemy behaviors that respond dynamically to player actions, facilitating strategic adjustments and ultimately providing a more challenging gaming experience.

4.2 Analysis of the Rationale and Adaptability of New Technology Usage

4.2.1 Analysis of the applicability of new technology

VR technology offers users profound experiences and expansive creative freedom, which aligns perfectly with children‘s need for appropriate space and tools to explore their imaginative thinking. By facilitating the development of spatial conceptualization from two-dimensional to three-dimensional perspectives, and even back to two-dimensional representations, VR technology leverages its inherent advantages. It captures children‘s hand movements, allowing them to express their creativity through simple finger gestures. Utilizing VR for children‘s creative endeavors provides greater freedom, enhances their imaginative capabilities, and resonates with the simplicity and enjoyment sought in toy design. ”AR and VR have the potential to fundamentally transform traditional teaching methodologies, cater to a wide array of learning needs, and provide personalized educational experiences. The future trajectory of AR and VR in education is likely to be characterized by a focus on enhancing user experience, improving accessibility, and achieving a seamless integration of these technologies into educational curricula” [9]. Moreover, the evolution of toys will also drive advancements in education, as the thoughtful integration of toys and technology is likely to influence educational models in the future.

However, after a comprehensive analysis of VR technology and its characteristics, the following three applicability issues can be identified:

1. Desktop virtual reality technology lacks a fully immersive experience, making it unsuitable for children.
2. Among display devices, head-mounted VR systems are the most suitable for children. In contrast, mobile head displays and external point display devices are not appropriate for child use. Mobile head displays often provide inadequate experiential feedback, while external display devices have limited convenience and can restrict movement. In contrast, all-in-one headsets offer unrestricted control and a superior experience.
3. Among VR interaction devices, motion-sensing equipment is most suitable for children. Child users require both simple interaction methods and tactile feedback from their hands to enhance the interaction experience and avoid confusion between the real and virtual worlds; thus, hand-based VR motion-sensing devices are the most appropriate choice.

3D printing technology is also applicable to toy design, providing children with a conversion experience from virtual to physical. Through interaction with toys, children can engage in real-time interactions with their environment and toys, gaining enhanced experiential feedback while showcasing their creativity. Such toy designs contribute to developing children‘s hand-eye coordination, cognitive skills, and stimulating their creative thinking. Furthermore, these new technologies can enhance children‘s reasoning abilities and logical thinking skills, including memory and attention.

When applying 3D printing technology to toys, it is crucial to ensure the safety and harmlessness of 3D printers for children. High-temperature materials or materials that release harmful gases should be avoided, and safety measures should be implemented to prevent accidental injury from the printer‘s casing and moving parts. The operation should be simplified, with interfaces designed for easy comprehension and use by children, streamlining the operational process while providing clear instructional guidelines and video tutorials to enable children to complete printing tasks independently. Eco-friendly and non-toxic printing materials should be selected to ensure children‘s health and safety; for instance, engineering plastics like ABS and PLA typically exhibit good printing results and safety. Instructions should guide children on safely removing support structures and performing simple cleaning and adjustments to the models.

If AI technology is integrated into toy design, safety must be the cornerstone. Additionally, ethical and moral considerations should not be overlooked, with an emphasis on the educational significance of the toys to promote children‘s holistic development. Mature and stable AI technologies should be chosen to ensure that products meet the diverse needs of children across various ages, genders, and interests, while pursuing innovation with attention to cultural sensitivity and sustainability.

However, due to the current weakness in technological innovation, there are still relatively few toy designs that integrate virtual reality, 3D printing, and artificial intelligence. Most applications remain within the realms of gaming and smart wearables. Nonetheless, these technologies undoubtedly promise to offer toys more interactive experiences that simulate real-world scenarios, attracting a broader range of potential users and allowing toys to fulfill their educational and entertaining roles effectively [2].

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4.2.2 Negative effects of new technology application

Although a preliminary study indicates that 30 minutes of daily VR use does not adversely affect the vision of children aged 10 to 12, concerns have increasingly shifted towards the overuse of screens and head-mounted displays (HMDs) [10]. Specifically, physical concerns focus on the heightened incidence of cybersickness, visual symptoms, obesity, and sleep disorders, as well as the impact of blue light on users‘ circadian rhythm systems. Furthermore, immersive gaming experiences may lead children to become more deeply engaged in virtual worlds. Both the World Health Organization and the International Classification of Diseases have issued warnings regarding the potential risks of gaming-related addiction and problematic behaviors. Nonetheless, the potential risks and ethical issues surrounding VR technologies (VRTs) and their hardware continue to emerge.

In addition to the potential hazards to vision and circadian systems, commercially available electronic noise-making toys also present certain noise-related risks. The auditory systems of users, particularly children, are still in a developmental stage, making the hazards of noise exposure significant and worthy of attention [11].

5. Conclusion

Due to the unique nature of toys, new technologies often do not make their first foray into the toy sector immediately upon their emergence. Instead, there is typically a period of maturation and application in other product domains before reaching a threshold suitable for toy applications. For new technologies or materials to be integrated into toy products, a demand analysis must first be conducted to confirm their value, followed by an applicability analysis of the technology. This process requires rigorous testing and validation to ensure reliability and safety.

Through the analysis of literature and specific toy cases, it is evident that VR/AR, 3D printing, and AI technologies have reached a mature stage of application and can be considered for integration into toy design. These technologies offer significant advantages in the toy domain; incorporating VR and 3D printing into toy design enables real-time interaction between children and toy products, enhancing their experiential engagement. This integration provides children ample opportunities to showcase their creative abilities, effectively fostering their hand-eye coordination, and cognitive skills, and stimulating their creative thinking. Furthermore, these technologies can bolster children‘s reasoning and logical thinking abilities, including memory and attention, thereby providing robust support for their holistic development.

However, these technologies currently lack specific design practices, and challenges remain in applying them to toy design. While time-limited screen and VR device usage allows children to experience the benefits of new technologies, excessive use may harm physical aspects such as vision and hearing, and could also negatively impact mental health. 3D printing, on the other hand, faces issues related to hardware operation, content design, and material safety. It is essential to further reduce the requirements for manual dexterity and to enhance safety standards to accommodate younger users effectively.

Currently, the integration of VR/AR, 3D printing, and artificial intelligence technologies into toy design remains relatively uncommon. However, these technologies hold the potential to offer richer interactive experiences, attracting a broader range of potential users and heralding a transformative shift in the toy industry. In the future, the application of suitable emerging technologies in toy design will be essential. Following thorough design processes, safety assessments, applicability analyses, and ethical considerations, these technologies can be innovatively integrated with toys, leading to the emergence of more exceptional products. As a result, toys are expected to become increasingly intelligent and personalized, stimulating children‘s creativity and imagination while providing them with richer and more diverse play experiences. The profound integration of toys and technology may even transform traditional educational models, further enhancing children‘s creativity, imagination, and overall development.

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