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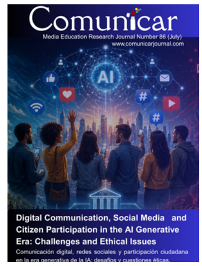


# Examining Artificial Intelligence Toys and Robots Features on Children´s Developmental Domains and Learning Skills

## Análisis de las características de los juguetes y robots con inteligencia artificial en los ámbitos del desarrollo y las habilidades de aprendizaje de los niños

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## ABSTRACT

AI toys and robots are among the many advanced technological devices in the Internet of Things (IoT) ecosystem. These technologies have been rapidly entering children´s everyday life (in play and learning). The IoT devices in the education domain can be characterized by their ability to connect via Wi-Fi or Bluetooth, their personalized design features and their embedded sensors. Only a few studies explored how these elements could be aligned with children's development and learning. This study aims to analyse AI toys and robots' characteristics and functionalities and its possible implication in early-childhood classrooms and other educational environments. Using structured observation with a specific guideline, a quantitative content analysis approach was used to examine the features of 20 AI toys and robots available on the market. The results suggest that in early childhood education contexts, AI toys could be introduced and used as an educational resource based on their potential for children's learning and play experience. The analysis reveals a co-presence amongst features related to children's socio-emotional development, the use of computer vision and natural language processing. Similarly, the characteristics that could promote physical and motor development through play are associated with the possibility of movement and gestures of the devices. The associations found between the functionalities present in AI toys and robots that incorporate AI suggest that they could be used for specific educational purposes, which is consistent with previous empirical studies, such as interactivity, thinking skills, physical development, and social learning. While the implication related to data capture indicates the necessity to strengthen privacy and address the risks associated with children as users.

## RESUMEN

Los juegos y *robots* que incorporan inteligencia artificial (IA) se encuentran entre los muchos dispositivos que usan tecnología avanzada y que son parte del ecosistema del Internet de las Cosas (IdC). Estas tecnologías se han ido incorporando rápidamente a la vida cotidiana de los niños y niñas (para el entretenimiento y el aprendizaje). Los dispositivos IdC en el ámbito educativo se caracterizan por su capacidad para conectarse a través de Wi-Fi o Bluetooth, su diseño personalizado y sus sensores integrados. Solo unos pocos estudios han explorado si y cómo estos elementos se adaptan al desarrollo y el aprendizaje de los niños y niñas. El objetivo de este estudio es analizar las características y funcionalidades de los juegos y robots con IA, así como sus posibles implicaciones en las aulas de educación infantil y otros entornos educativos. Se emplea un análisis del contenido mediante observación estructurada y un enfoque de análisis cuantitativo para examinar las características de 20 juegos y robots con IA disponibles en el mercado. Los resultados sugieren que en algunos contextos de educación infantil, se podrían introducir y usar juegos con IA como recurso educativo, en función de su potencial para el aprendizaje y de la experiencia de juego de los niños. El análisis revela una copresencia en estos juegos de elementos relacionados con el desarrollo socioemocional infantil, el uso de visión por ordenador y del procesamiento del lenguaje natural Igualmente, las características que podrían


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promocionar a través del juego el desarrollo físico y motor se asocian con la posibilidad de movimiento y gestos de los dispositivos. Las asociaciones encontradas entre las funcionalidades presentes en los juegos y *robots* que incorporan AI sugieren que podrían utilizarse con fines educativos concretos, lo que concuerda con estudios empíricos previos, tales como la interactividad, las habilidades de pensamiento, el desarrollo físico y el aprendizaje social. Por otra parte, las implicaciones asociadas a la captura de datos indican la necesidad de reforzar la privacidad de estos juegos y abordar los riesgos asociados a su uso.

KEYWORDS | PALABRAS CLAVE
AI Toys, Educational Robots, Developmental Domains, Children, Content Analysis.
Juguetes con IA, robots educativos, áreas de desarrollo, niños, análisis de contenido.

## 1. Introduction

Advanced digital play in children's lives involves various technological devices, such as digital and/or intelligent toys and robots. Their roles in children's play and learning experiences are diversified within different spheres: home, school, and play space. The terms intelligent or digital toys and robots are interchangeably used in slightly different contexts; the term ' intelligent or digital toys' is usually used solely to refer to play activities (Johnson & Christie, 2009), while 'robots' are used for specific purposes, such as educational and therapeutic purposes (Torpegaard et al., 2022). Intelligence toys and robots are known as Internet of Toys (IoToys) and a part of the Internet of Things (IoT) ecosystem. IoT includes diverse domains like healthcare (Ray et al., 2020), smart city and/infrastructure (Subahi & Bouazza, 2020) and education (De La Guia et al., 2016). AI toys and robots in the education domain use the internet, sensors, and software to operate, navigate, and interact with users (Brito et al., 2018). The connections embedded in the toys are often designed to share data, such as children's learning activities, through the toy's or robot's application that parents can access.

Previous study of children's interaction with intelligence toys and robots with their learning experience was investigated by Berson et al. (2023), who used intelligence robots to teach children spatial reasoning and basic programming in the early learning context. Another study by de Castro Rodrigues et al. (2022) explored AI interfaces in children's games to investigate its correlation with children's literacy skills. Most studies of AI toys and robots have been conducted in school settings (Berson et al., 2023; de Castro Rodrigues et al., 2022). However, as children's play frequently occurs at home and in other public spaces, these environments should also be explored in future research.

A number of scholars have discussed the relationship between play and children's development. Piagetian theory highlighted that play contributes to children's intellectual or cognitive development throughout their sensorimotor stage (0 to 2 years), where children undergo spontaneous reactions (i.e., repetitive reflexes) to their environment and the preoperational stage (2 to 7 years) when they develop abstract mental processes (Blaisdell, 2023). In the preoperational stage, children actively explore, test, and adapt their understanding of their surroundings through repeated interactions, known as assimilation (Wilks et al., 2010). The assimilation process evolves around the physiological and psychological aspects of children's development, which underscores Piaget's view of the construction of cognitive development through children's way of interacting with their environment as they grow.

In Vygotsky's theory (1967), play is a primary driver of a child's development. It is shaped through children's internal transformation of objects, meaning making with their environment and adults (i.e. parents, caregivers, and teachers) around them. He added that through play; children strive to surpass their usual behaviour; thereby, they grow through play activities; hence, only in this sense can play be considered a leading activity that shapes children's development. However, the direct outcomes of play may not be immediately apparent, and only through deep internal analysis can we understand its impact and significance in preschool development. He highlighted the importance of symbolic play, viewing it as a form of role-playing where children practice social norms and internalise cultural tools like language. He stated that imagination and symbolisation in play are crucial for children to distinguish meaning from reality, thereby promoting abstract thinking (i.e., imagination and creativity). Consequently, Vygotsky emphasised the social and cultural dimensions of play on their significance to children´s development.

Piaget considered play primarily as an individual activity that mirrors cognitive development. In contrast, Vygotsky underscored the social and interactive aspects of play, highlighting that cognitive development is significantly shaped by social interactions. Piaget's perspective centred more on internal cognitive processes such as schemas, assimilation, and accommodation (meaning making between objects and children's prior knowledge). On the other hand, Vygotsky outlined that social mediation is important to promote children's cognitive abilities (i.e. strategic and critical thinking). Additionally, Vygotsky emphasised the importance of language and culture in play, viewing them as tools for children to internalise societal norms (i.e. cultural identity, language and values).

Drawing from Piaget and Vygotsky's foundational theories of play and development, both theorists share five key areas of children's development that will be further examined in this study. These areas include cognitive and language development, socio-emotional, physical and motor skills, and the acquisition of general knowledge. Although general knowledge is not explicitly highlighted by either theorist, they stress the importance of the environment and the assimilation process to accommodate children's overall development.

The study of children's digital play with advanced technologies has been explored across different fields, such as media, robotics or child-robot interaction, game and industrial design, sociology, psychology, and education (Marsh et al., 2016). The alignment between device characteristics and the dimensions of children's socio-emotional and physical and motor development had not been studied in this age group nor in the naturalistic early-childhood educational field. Previous IoToys studies have generally focused on older populations, controlled environments, and single-modality sensors. Recent studies exploring the topic of AI toys and robots come from multiple perspectives: the affordance of smart and/or digital toys for children aged 3 to 12 years old focused on specific design opportunities through an analysis of an online catalogue (Wang et al., 2021), evolution of AI-powered toys from academic and industrial landscapes (Xiao & Gonçalves, 2025), and parents' perception on their children use of IoToys from the content, academic performance, and time of play aspects (Ling et al., 2026). This study contributes to investigate the tangible AI toys and robots' possible implications to children´s learning and play experiences through Piaget´s and Vygotsky´s developmental theories, both to address educational practices and to support a more child-centred pedagogical design of new tools, that meet children´s developmental needs.

There is currently limited research on commercially intelligent toys and robots for educators and families who purchase via online platforms. Despite their growing presence, little is known about how these devices are used for learning and entertainment in natural settings, such as homes, schools, and play spaces. While the EU (European Union) has recently strengthened safety standards, specifically through the December 2025 Toy Safety Regulation revision introducing the Digital Product Passport (DPP) and Regulation (EU) 2024/2847 on cybersecurity (European Parliament, 2025; European Parliament & Council of the European Union, 2024). This study analyses the features of intelligent toys to understand their influence on children's play and development. The findings aim to inform pedagogical uses, promote the design of developmentally appropriate products for children, and ensure compliance with evolving EU safety and cybersecurity regulations.

The study sets out to examine specific features related to socio-emotional and physical motor development and their possible ways these technologies shape children´s play and learning experience. To address the objectives of this study, we focused on the following research questions:

- RQ1: What are the characteristics of AI toys and robots?
- RQ2: What are the possible associations among features related to children's socio-emotional development that can be used in an educational context?
- RQ3: What are the possible associations among features related to children's physical and motor development that can be used in an educational context?

## 2. Literature Review and Theoretical Framework

### 2.1. AI Toys and Robots

Most of the latest AI-based robots in early childhood education (ECE) are used in healthcare (Beccaluva et al., 2022), such as the one for autism spectrum disorder (ASD) therapy in clinical context (Yi et al., 2024). Another context of AI-based robots or intelligence robots are designed as a social agent (hereafter known as social robot) as a companion to help children (de Jong et al., 2020; Henschel et al., 2021).

In the field of education, educational robots are designed to support learning for students starting in kindergarten to higher education. Some of the AI-based robots in early learning context have been discussed in the previous studies include: iRobiQ, NAO, KASPAR, Keepon, AIBO, IROMEC, iCat, Matatalab coding set, Anki Cogni Toys, Google's alpha intelligence robot, Sony's Aibo, and Olpay Cady (Podpečan, 2023; Wang et al., 2021; Yang et al., 2022). Only a few of the abovementioned robots are used in the school setting, and most of them are experimented in the laboratory and are not available in the market (Yi et al., 2024). The robots intended for teaching themselves provide varied options; some accommodate direct use of robots (without media application or tool), and some provide indirect use (through mobile or tablet applications) to operate and navigate the robots, like Sphero Mini and Moxie.

AI toys and robots for children are designed using certain levels of AI systems (Machine Learning, Deep Learning, Natural Language Processing, and Computer Vision) that enable to function advanced tasks like face and emotion expression recognition, voice and touch sensors command into robot action, personalised learning, multilingual language features, and so on (Aguilera et al., 2024). Besides the AI system, the physical characteristics of AI toys and robots toward its potential for children's developmental and learning skills are also crucial to examine (Hoffman & Ju, 2014; Lund, 2001).

The physical characteristics of toys are identified based on their components (i.e. camera, speaker, accessories to enhance play experience, and guidance book), colours and textures, dimension and weight, and movement and gestures. The categorisation of toys and robots´ functionality in this current research focuses on the AI features embedded in the system, which consist of data processing, natural language processing, personalised learning, intelligence behaviour, and computer vision. This is followed by the physical characteristics aspect and developmental and learning skills supported by their intelligence features.

### 2.2. Children´s Play with AI Toys and Robots

Children's play that involves digital technologies is classified into more specific digital play frameworks and types (Bird & Edwards, 2015; Marsh et al., 2016). Defining children's age range in the toys and robots' industry is pivotal before continuing an in-depth analysis of its use in their learning and play. A decade ago, the distribution and availability of edutainment robots for children aged zero to six years was comparably lower than any other age range (seven to 16 years old) (Lund, 2001). They revealed that only four robots were designed and developed for children aged three to six years, three of which were designed to teach children basic programming skills, namely Doc, Kibo, Cubetto, and Dino (for edutainment).

Ríos Rincón et al. (2022) explored children's play with robots by analysing children's imaginations of the robot's characteristics. They highlighted some characteristics related to design, such as anthropomorphism (tough, strong, and has control), as well as robots' ability to express some sort of emotion or personality. Furthermore, they added that interaction between children and robots (child-robot interaction) can occur if there is acceptability from the child's side to interact with the robot.

The interaction (acceptance) between children and robots is affected by the robot's appearance, social behaviour, and adaptive behaviour (de Jong et al., 2020). A study showed that children's acceptance of domestic social robots can be thoroughly analysed through longitudinal observation of their repeated use (behavioural), intention, interest, and intensity of using the robots (De Jong et al., 2024).

In our previous systematic review, we found a lack of exploration of socio-emotional and physical and motor development in studies related to children's digital play using advanced technologies. Therefore, this current study aims to understand the association of co-occurrence-specific features that potentially influence children's socio-emotional and physical and motor development. AI toys and robots are operated and tested without direct interaction with the children.

The extent to which the claims given by the developers regarding the features of the toys and robots are scientifically proven by experts in the field (child psychology, AI and robotics, and pedagogy). This content analysis was carried out to ensure the proper age and developmentally appropriate selection of AI toys and robots for the next stage of the experimental study with children.

## 3. Methodology

### 3.1. Research Design

This study uses systematic content analysis conducted through structured observation to examine the features and functionalities of AI toys and robots' samples within an interdisciplinary lens. A quantitative approach is applied, building on the evolution of content analysis methods that have previously been used to analyse traditional media, such as television, as well as interactive media like social media and movement-based gameplay (Krippendor, 2004). Content analysis allows systematic examination of how AI toys aligned with established developmental dimensions and learning opportunities in early childhood educational contexts. The methodological procedure followed in this study is outlined in Figure 1 and summarized in Table 1.

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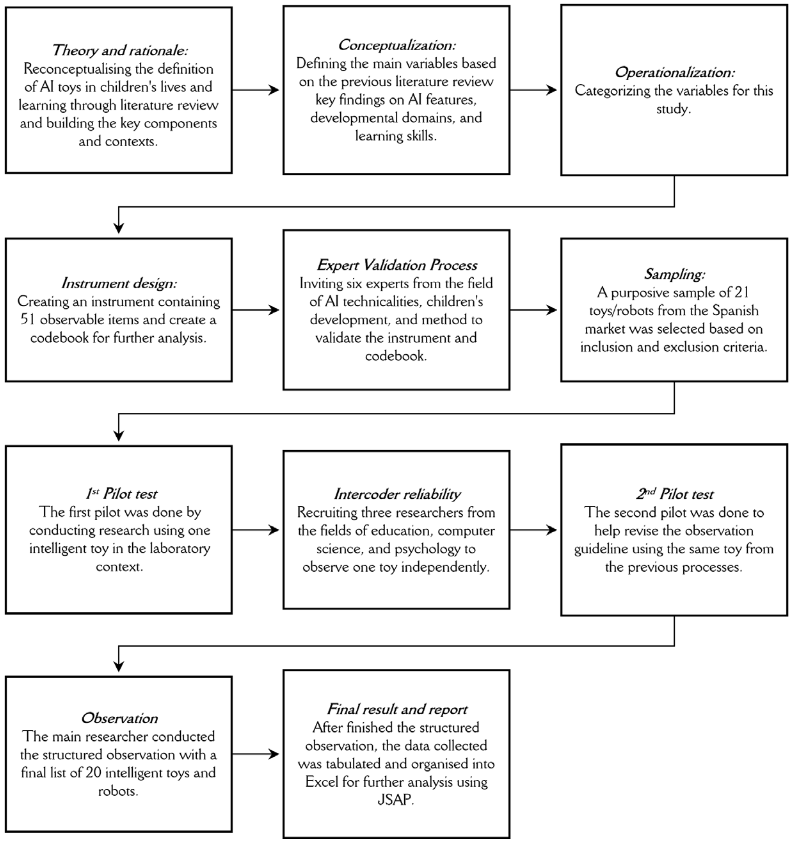
Figure 1: The Content Analysis Process Builds Upon the Framework Described by Skalski et al. (2017).




## 3.2. Sample

The study employs purposive sampling to select items based on specific criteria (see Table 1). After reviewing e-commerce websites and online catalogues, including Miniland Education, Amazon, Google Store, Twinscience.com, heycurio.com, moxierobot.com, and theconversation.com, we selected 20 AI toys and robots. The unit of analysis was one toy/robot. The word strings used for searching were "Intelligence toys/robots", "Toys using Artificial Intelligence", "Smart intelligence toys/robots", "AI Toys", "AI robots", "intelligence toys/robots for 6 years old", and "Toys/robots with artificial intelligence for children". Specific criteria are defined for final selection (see Table 1).

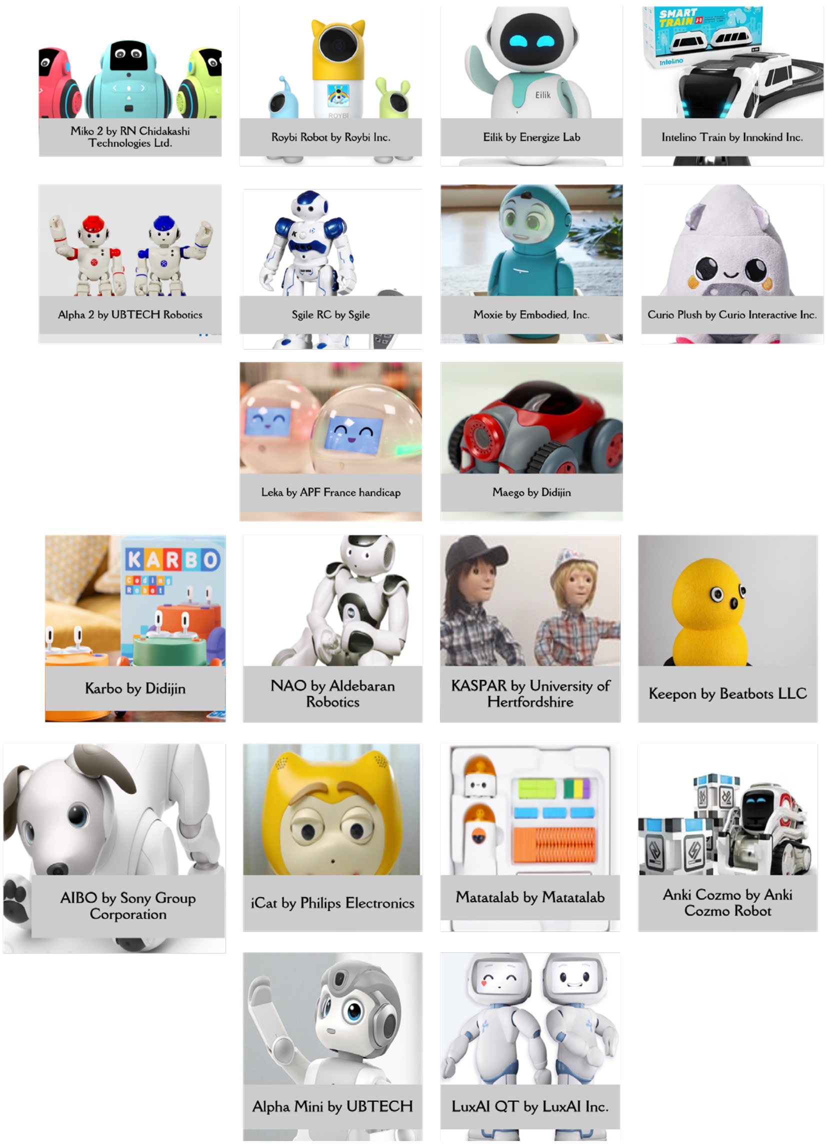
| Table 1: Inclusion and Exclusion Criteria. | |
|---|---|
| **Inclusion Criteria** | |
| 1. | An intelligence toy or robot is embedded with advanced technology (i.e. personalised learning and face/voice recognition). |
| 2. | It is targeted at children under six years old. |
| 3. | From the catalogue description, it is described as an intelligence toy or robot with AI features. |
| **Exclusion Criteria** | |
| 1. | The toy or robot is not tangible (i.e. only application). |
| 2. | It is targeted at all ages, or children above six years old. |
| 3. | It does not have a description on their website about the specific AI features of the toys and robots. |

The final sample includes six physical AI toys and robots, which were inspected in the laboratory, and 14 more were analysed based on the multimedia information available online (due to its excessive cost or it was not yet being available for sale in Europe). Below is a summary of the selected AI toys and robots for this study (see Table 2) and a visual description in Figure 2.

Table 2: Sample of 20 AI Toys and Robots.

| AI toys and Robots Analysed in a Laboratory | AI toys and Robots Analysed Using Online Information |
|---|---|
| | 7. Moxie Robot |
| | 8. Curio Plush |
| | 9. Leka Robot |
| | 10. Maego |
| 1. Miko 2 | 11. Karbo |
| 2. Roybi Robot | 12. NAO |
| 3. Eilik | 13. KASPAR |
| 4. Intelino Train | 14. Keepon |
| 5. Alpha 2 | 15. AIBO |
| 6. Sgile RC | 16. iCat |
| | 17. Matatalab coding set |
| | 18. Anki Cozmo |
| | 19. Alpha Mini |
| | 20. LuxAI QT Robot |

Figure 2: AI Toys and Robots.



## 3. Data Collection

This study uses a structured observation tool developed specifically for examining AI toys and robots features on children's developmental domains and learning skills using an integrated interdisciplinary lens spanning child development, education, and child–computer interaction (Appendix A). The observation guideline is designed to code the characteristic, content, and functionality of Artificial Intelligence (AI) Toys and Robots; it contains four parts; first, general information, second, physical characteristics of the toys or robots, third, AI features and functionalities, and fourth, the features related to children's developmental domains contributed to the interaction with AI toys or robots.

The AI functionalities were theoretically formulated and it covers five aspects related to data processing (its capacity to interpret, process, and share users´ data) (Scotti, 2020), intelligent behaviour (system that enable robots to simulate humans' task) (Liao et al., 2025), Natural Language Processing (Jiang et al., 2023), personalised learning (system that store and interpret children's data in learning and performance analytics to personalized contents and tasks) (Yi et al., 2024), and computer vision (a system that can detect object motion) (McStay & Rosner, 2021).

The chosen categories for each targeted developmental domains and learning skills are based on the previous empirical studies related to digital play (Xiong et al., 2022), games-based learning in children's development (Amorim et al., 2020), AI toys and robots and its relation to children's learning and developmental domains (de Castro Rodrigues et al., 2022), and the research gap found related to physical-motor developments and socio-emotional skills in children's digital play and games-based learning.

Six experts from diverse areas of expertise contributed to the two-stage validation process and testing of the instrument prior to its use in content analysis data collection. In the first stage, the initial draft was reviewed and validated by two experts specializing in child development and artificial intelligence (AI) technicalities. The second draft was then validated by four additional researchers —two men and two women— experts in distinct fields: research methodology, children's health and wellbeing, AI and robotics, and teaching pedagogy. The development and validation process spanned two months, from September to October 2024.

The instrument was piloted using a robot, which was observed by three independent researchers in the field of education science, psychology, and computer science, obtaining a good agreement (based on Cohen's Kappa threshold and percent agreement. The random subsample (one robot) used in this stage is between 5% of the sample (*N*=20) and it was excluded from the final sample of this study. see Table 3).

**Table 3: Inter-rater Agreement.**

| Percent Agreement | Scott's Pi | Cohen's Kappa | Krippendorff Alpha (nominal) | N Agreements | N Disagreements | N Cases | N Decisions |
|---|---|---|---|---|---|---|---|
| 92.2% | 0.842 | 0.842 | 0.843 | 47 | 4 | 51 | 102 |

The structured observation for the sample of 20 Artificial Intelligence (AI) Toys and Robots was done by one researcher who is an expert in early learning and toys' evaluation. The final observation guideline (see Appendix A) includes 18 items associated with the physical characteristics of the toy/robot, 17 AI functionalities and 16 items of developmental domains (Table 4). The data collection was conducted in November 2024.

**Table 4: Summary of Sub-items of Observation.**

| Constructs | Dimensions and Codes | Total Number of Items |
|---|---|---|
| Physical Characteristics: | 1. Components (C)<br>2. Colours and Textures (CT)<br>3. Dimension and Weight (DW)<br>4. Movement and Gestures (MG) | 18 items. |
| AI Functionalities: | 5. Data Processing (DP)<br>6. Intelligence Behaviour (IB)<br>7. Natural Language Processing (NLP)<br>8. Personalised Learning (PL)<br>9. Computer Vision (CV) | 17 items. |
| Developmental Domains: | 10. Cognitive and Language Developments (CLD<br>11. Socio-Emotional Developments (SED)<br>12. Physical and Motor Developments (PMD)<br>13. General Knowledge Acquisition (GKA) | 16 items. |

Table 5 summarizes content analysis observation checklist *(√ is presence and – is non-presence)* of all 18 items associated with the physical characteristics of the toy/robot, 17 AI functionalities and 16 items of developmental domain.

Table 5: Summary of Content Analysis Observation Checklist (√ is presence and – is non-presence).

| AI Toys and Robots | Physical Characteristics | | | | AI Functionalities | | | | | Developmental and Learning | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | CT | DW | MG | DP | IB | NLP | PL | CV | CLD | SED | PMD | GKA |
| Miko 2 | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| Roybi Robot | √ | √ | √ | - | √ | √ | √ | √ | √ | √ | √ | - | √ |
| Eilik | √ | √ | √ | √ | √ | √ | √ | - | √ | √ | √ | √ | √ |
| Intelino Train | √ | √ | √ | √ | - | - | - | | - | √ | - | √ | √ |
| Alpha 2 | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | - | √ | √ |
| Sgile RC | √ | √ | √ | √ | - | - | - | - | - | - | - | | - |
| Moxie Robot | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| Curio Plush | √ | √ | √ | - | √ | √ | √ | √ | - | | - | - | √ |
| Leka Robot | √ | √ | √ | √ | - | √ | - | √ | √ | √ | √ | √ | √ |
| Maego | √ | √ | √ | √ | √ | √ | - | - | √ | √ | - | √ | - |
| Karbo | √ | √ | √ | √ | - | √ | - | - | - | | - | √ | √ |
| NAO | √ | √ | - | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| KASPAR | √ | √ | √ | √ | √ | √ | - | - | √ | - | √ | √ | - |
| Keepon | √ | √ | √ | - | √ | √ | - | - | √ | - | √ | √ | √ |
| AIBO | √ | √ | √ | √ | √ | √ | √ | - | √ | - | √ | √ | √ |
| iCat | √ | √ | √ | √ | √ | √ | √ | √ | √ | - | √ | √ | - |
| Matatalab coding set | √ | √ | √ | √ | - | √ | - | √ | - | √ | - | √ | - |
| Anki Cozmo | √ | √ | √ | √ | √ | √ | - | √ | √ | √ | - | √ | √ |
| Alpha Mini | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| LuxAI QT Robot | √ | √ | - | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |

## 3.4. Data Analysis

The structured observation checklist tool observed the presence (1) and absence (0) of features and functionalities when operating AI toys and robots in the laboratory context and examining their features from online catalogue. This study focuses on category-based co-occurrence using contingency tables to measure categorical variables of intelligence toys and robots' features. There are different types of co-occurrences in content analysis, such as surface co-occurrence, textual co-occurrence, semantic co-occurrence, syntactic co-occurrence and category-based (thematic) co-occurrence (Skalski et al., 2017). The JASP 0.19.3 package has been used to analyse the relationship between dichotomous variables (0 and 1) and evaluate co-occurrence.

Two tests were used: the Chi-square test ($\chi^2$) and the Likelihood Ratio (LR) test. The Pearson model and standardised residuals (SR) have been used as an additional measure to evaluate the magnitude of the effect, providing an additional layer of insight into the relationship between the variables. Specifically, SR offers a more nuanced understanding of the effect size, allowing for a more precise interpretation of results. Results with a p-value less than or equal to 0.05 were considered significant.

The Pearson Chi-squared statistics present the evidence associated among categories (measured in a two-way contingency table). The Pearson standardised residual allows the exploration of value from each cell that is inconsistent with the expected (Beh, 2012). The features being explored in this study are related to children´s socio-emotional development (SED) and physical and motor development (PMD). While the observed AI features in toys and robots are data processing (DP), intelligence behaviour (IB), natural language processing (PL), personalised learning (PL), movement and gesture (MG), and computer vision (CV).

## 4. Findings

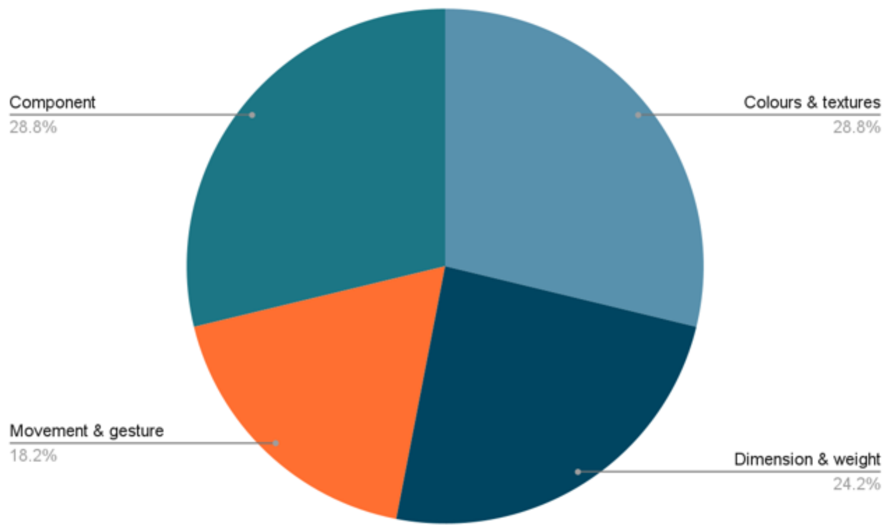
The results suggest that AI toys and robots as play and learning tools that are bounded with their design features (i.e., personalized activity and connectivity) and AI technicalities (i.e., data capture and sensors). Therefore, the results are presented through an interdisciplinary lens and connected with educational implications of AI toys and robots' design elements and AI features. Specific focus on exploring the connection with children's socio-emotional and physical and motor development and learning in the educational domain are revealed in this section.

RQ1. What are the characteristics of AI toys and robots?

The findings reveal various physical characteristics in AI toys and robots related to children's learning and play activities. Most toys and robots include recognisable switch buttons allowing children to start operating them easily. About 65% have microphones, 85% have built-in speakers, and 95% feature cameras for recording, taking photos, video calls, and recognising gestures or movements. Play-enhancing accessories such as stickers, additional spare parts, and a user manual are included in the packaging or in the online description of 20 AI toys and robots.

AI toys and robots are also usually visually and tactilely engaging. The data shows that 95% use contrasting colours to highlight features such as switches, connectors, buttons, and speakers. Additionally, 90% incorporate varied textures and materials for different parts of toys and robots. The figure below provides a summary of the physical characteristics of the 20 AI toys and robots in comparison of the overall aspects (see Figure 3).

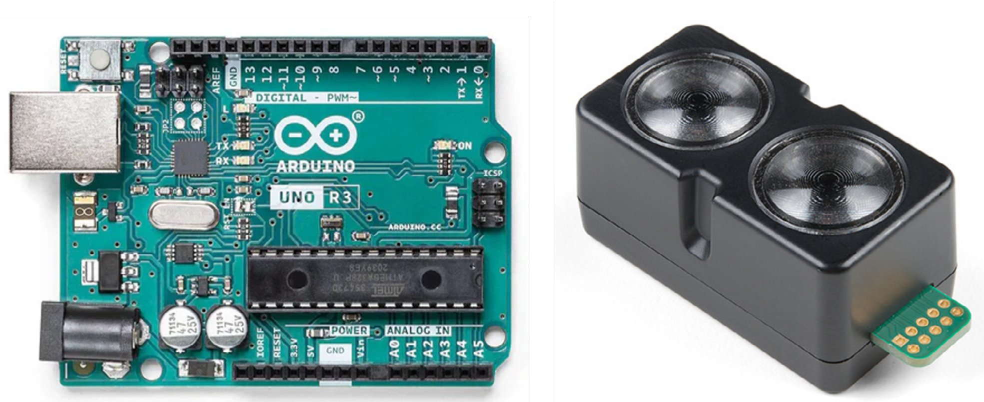
**Figure 3: Summary of AI Toys and Robots´ Physical Characteristics.**




Exploring and describing the physical characteristics of toys and robots is the starting point of analysis to examine the relation with AI features and functionalities. Besides, the physical characteristics such as colours, textures, dimension, weight, movement, and gestures, also help to understand its relation to educational opportunities and limits for children's experience in their play and learning. The minimum and maximum weight and size of AI toys and robots are established to classify their appropriateness dimension for children use. Additionally, all toys and robots provide English as a medium of instruction (audio and text guides); apart from it, in some cases (*N*=9) also other languages are supported, namely Spanish, French, Japanese, Chinese, Dutch, Portuguese, and 30 other languages, which are not specifically classified.

The classification of features that are linked with the user's movement and gesture consists of three aspects: moving without moving around, moving within surroundings, and using different speed options. In the sample observed, AI toys and robots' movement features include a variety of sensors: Leka uses Arduino microcontroller, Intelino uses proximity and speed sensors with 32-bit ARM microcontroller, Maego uses LiDar (Light Detection and Ranging) (see Figure 4) system to measure distances of objects, NAO uses sonar (sound navigation system) and inertial measurement (IMUs), and Alpha mini uses Time-of-Flight (ToF) Infrared (IR) sensors. Each sensor has specific strengths and weaknesses that directly impact the functionality, cost of production, and price of toys and robots. (See Figure 4)

**Figure 4: An Example of Arduino Uno R3 (left) and Garmin Lidar Lite V3 (right).**




Source: Wikimedia commons (left) and Sparkfun Electronics (right)

RQ2. What are the possible associations among features related to children's socio-emotional development to be used in an educational context?

The opportunities for AI toys and robots to contribute to the development of socio-emotional activities (SED) are assessed based on their co-occurrence with four characteristics of AI: movement and gesture (MG), intelligence behaviour (IB), natural language processing (NLP), and computer vision (CV) (see Table 6). This aims to identify which features could be associated with SED.

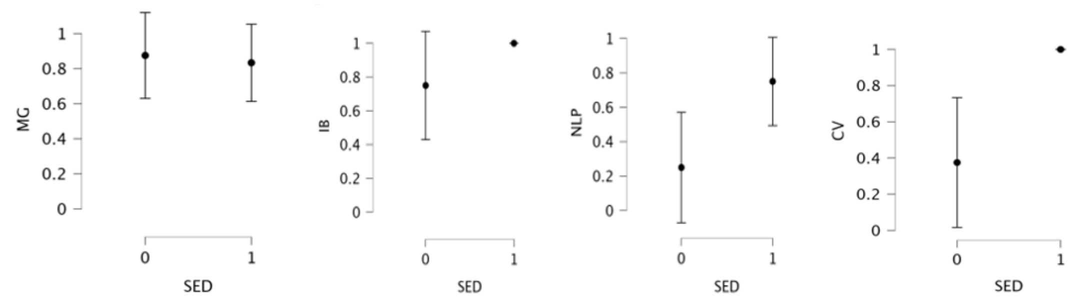
**Table 6: Summary of Contingency Tables and Chi-Squared Tests.**

| | SED | | 0 | | 1 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | n° | Pearson Residuals | SR | Pearson Residuals | SR | | Chi-Squared ($X^2$) Tests | Likelihood Ratio Test |
| MG | 0 | 1 | -0.183 | -0.256 | 0.149 | 0.256 | Value | 0.065 | 0.067 |
| | 1 | 7 | 0.077 | 0.256 | -0.063 | -0.256 | p | 0.798 | 0.796 |
| IB | 0 | 2 | 1.342 | 1.826 | -1.095 | -1.826 | Value | 3.333 | 4.006 |
| | 1 | 6 | -0.447 | -1.826 | 0.365 | 1.826 | p | 0.068 | 0.045 |
| NLP | 0 | 6 | 1.265 | 2.202 | -1.033 | -2.202 | Value | 4.848 | 5.032 |
| | 1 | 2 | -1.144 | -2.202 | 0.934 | 2.202 | p | 0.028 | 0.025 |
| CV | 0 | 5 | 2.121 | 3.162 | -1.732 | -3.162 | Values | 10.000 | 11.908 |
| | 1 | 3 | -1.225 | -3.162 | 1.000 | 3.162 | p | 0.002 | < .001 |

The result of the statistical analysis above is based on the Pearson residual *sr* value and chi-square test. The Pearson residual (*sr*) values, the higher the absolute residual value, the more that association contributes to the Chi-square statistic (Beh, 2012). Outliers (standard residual greater than 2 or less than -2) may result from the limited sample. There are two highlights of associations; first, there is a strong positive association between SED (socio-emotional feature) and CV (computer vision feature) $p=0.002$, $sr=3.16$ and second, a positive significant association between SED and NLP (natural language processing feature) $p=0.028$, $sr= 2.2$. The result between IB (intelligence behaviour feature) and SED suggests a close significance association, with $p=0.068$ and $sr= 1.82$. Lastly, there is no significant co-occurrence association between MG (movement and gesture feature) and SED, further fieldwork study to explore more concrete and measurable associations between the features are necessary.

The analysis shows the co-occurrence of socio-emotional (SED) features with computer vision (CV) elements in AI toys and robots and with natural language processing (NLP) (see Figure 5). The existence of CV elements, related to affective computing (sensors, cameras, etc.), suggest the capabilities of toys and robots, for example, to recognise children's emotion expression through face recognition or detect a certain extent of children's engagement through bodily movement recognition. The co-occurrence between SED with CV when it is paired with NLP suggests socio-emotional functionalities in AI toys and robots is most realized through object or movement sensing and dialogue. The kind of features that enable recognition, response and personalization. The implication related to data capture linked with the necessity to tighten the privacy and risks-related in children´s context as users.

**Figure 5: Interval Plots Show that the Values are Widely Different between SED (0 and 1) and IB, NLP, and CV.**




RQ3. What are the potential associations among features related to children's physical and motor development to be used in an educational context?

The potential of physical and motor development (PMD) to influence children's learning and development is explored by examining its co-occurrence with four AI features: movement and gesture (MG), intelligent behaviour (IB), personalized learning (PL), and computer vision (CV) (see Table 7). This analysis aims to identify which of these AI features are most closely associated with PMD.

**Table 7: Summary of Contingency Tables and Chi-Squared Tests.**

| | PMD | 0 | | 1 | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pearson residuals | SR | Pearson residuals | SR | | Chi-Squared ($X^2$) Tests | Likelihood Ratio Test |
| MG | 0 | 3.104 | 3.549 | -1.035 | -3.549 | Value | 12.593 | 9.184 |
| | 1 | -1.304 | -3.549 | 0.435 | 3.549 | p | < .001 | 0.002 |
| IB | 0 | -0.447 | -0.497 | 0.149 | 0.497 | Value | 0.247 | 0.445 |
| | 1 | 0.149 | 0.497 | -0.050 | -0.497 | p | 0.619 | 0.505 |
| PL | 0 | -0.837 | -1.094 | 0.279 | 1.094 | Value | 1.197 | 1.841 |
| | 1 | 0.614 | 1.094 | -0.205 | -1.094 | p | 0.274 | 0.175 |
| CV | 0 | 0.707 | 0.861 | -0.236 | -0.861 | Value | 0.741 | 0.651 |
| | 1 | -0.408 | -0.861 | 0.136 | 0.861 | p | 0.389 | 0.420 |

The inferential analysis above suggests only the movement and gesture (MG) feature shows a strong significant association with physical and motor development potential (PMD) *p=< .001*, and it is confirmed by the value of Pearson standardized residual *sr=3.5*. The result suggests a weak co-occurrence association with the other three categories (IB, PL, and CV); however, personalized learning (PL) features can be explored more since it is close to the minimum value in Pearson standardized with *p=0.274*.

It emphasizes the relationship and co-occurrence of mutual direction on physical and motor development (PMD) features with movement and gesture (MG) in AI toys and robots. This suggests that PMD is most operationalized through embodied interaction. The MG features could support coordinated bodily action, for example, imitation or timed movement. This finding reveals a design convention in which PMD is addressed through activity prompting rather than through structured motor-skill scaffolding (i.e., sensor-informed feedback). Despite the lack of significant association between PL and PMD, the data offers valuable insights for qualitatively assessing contributions to physical and motor development domains.

## 5. Discussion

The examination of observed features on intelligence toys and robots is addressed through describing and evaluating their physical characteristics, as well as possible association amongst targeted developmental domains (socio-emotional and physical-motor development). In the first research question, by describing AI toys and robots´ physical characteristics, we gain insight into how tangible components of intelligence toys and robots relate to specific AI functionalities.

The second research question explores how the integration of movement and gesture (MG), intelligence behaviour (IB), natural language processing (NLP), and computer vision (CV) features drives the potential for AI toys and robots in children´s socio-emotional development (SED). The analysis reveals significant positive associations between SED, CV, and NLP. These findings align with Arıcı (2023), who presented how Augmented Reality (AR) enhances children's engagement with their surroundings by using computer vision (CV) features to identify objects and foster metaphoric perception. Specifically, CV enables devices to process environmental cues via embedded cameras, allowing the system to react dynamically to detected objects or movements.

By processing and reacting to physical cues, these technologies create interactive experiences that, according to Coninx et al. (2016) and Rudenko et al. (2024), could foster companionship, resilience, and prosocial behaviour in kindergarten. However, to confirm the practical effectiveness and implications of these interactions for early learning requires further investigation through in-depth observational fieldwork. The findings from study on social robots and children's social learning suggest the need to personalize play-scenarios based on a child's level of sociability, considering their interaction models to strengthen interactions between children and their peers (Chung, 2025).

Additionally, the NLP features are linked to Vygotsky's theory (1967) by positioning language as a cultural tool. Robots that engage in dialogue support enable children to practice conversational turn-taking and internalise social communicational rules. The NLP could facilitate collaborative learning and problem-solving, reproducing the interactions that Vygotsky described as fundamental to the zone of proximal development (ZPD). Previous studies show alignment on revealing that NLP in educational robots can encourage collaborative learning in kindergarten by facilitating turn-taking, prompting students to refine ideas, and accommodate critical thinking and communication skills through guiding questions (Angeli & Valanides, 2020; Younis et al., 2023).

The third research question proposes the possible association between physical and motor development (PMD) features with the functionalities of movement and gesture (MG), intelligence behaviours (IB), personalised learning (PL), and computer vision (CV). The result suggests a strong positive association between PMD and MG. Suppose AI toys and robots claim to enhance children's physical and motor development. In that case, it is necessary to identify the complexity of movement and gesture functionality that can enhance children's play and its ability to prove the claim's veracity (enhancing physical and motor development). These findings align with the previous study by Mayoral and colleagues (2024) that explored assistive robots in promoting physical development with children aged 2 to 3 years old children (sample n=8), based on the measurement of ankles' movement, acceleration, velocity, and overall children's overground movement (Mayoral et al., 2024).

Robots capable of moving or responding to children's physical actions could create opportunities for imaginative role-play. A robot that dances can be impregnated by the child with symbolic meaning, becoming a peer or character in a tale. The results of a recent study would be consistent with this idea. In nursery settings, educational robots were utilized with 350 children aged 4 to 8 years old, showing that robot-mediated play stimulated more varied and complex social interactions than traditional analogue activities; cooperative play appeared in 44% of robot sessions (Panelli et al., 2025).

Overall, the statistical findings open for further analysis in some categories in each research question, for instance, the weak and moderate associations between feature personalised learning (PL) in the AI toys and robots with physical and motor development (PMD), as well as how toys and robots produce intelligence behaviour (IB) due to its existence or support of computer vision feature. Those two are potential relationships to be explored in future studies.

The practical contributions of this study address three key areas: educational settings, product design, and policy regulation. In the learning experience, the study encourages educators and practitioners by providing a validated observation checklist. Teachers can utilize this tool not only to select AI toys and robots that align with specific pedagogical objectives but also to assess how these devices support individual pupils' developmental needs. Then, from the designer and developers' aspect, the findings offer evidence-based guidelines for creating age-and-developmentally appropriate technologies for children.

By understanding the possible association between specific AI features and child development, the industry can move beyond entertainment-focused products toward designing ethical, developmentally supportive learning companions. Lastly, the finding informs the European Union Toy Safety by offering data regarding the features of internet connected toys. These insights are essential for refining standards related to cybersecurity and data privacy, ensuring that regulation keeps pace with the rapid evolution of internet connected toys.

## 6. Conclusion

This study examined the functionalities of AI features in children's toys and robots to relate the embedded features with its physical and social affordances in children's digital play and its potency in accommodating children's motor, cognitive, socio-emotional developmental domains and learning skills (language and general knowledge acquisition). The quantitative content analysis revealed the relationships through proposed association. Departing from the need to answer research gaps and testing the claim of most AI toys and robots in accommodating children's developmental and learning skills.

Our finding suggests that co-occurrences of AI features in children´s toys and robots have potential functionality relationships with features that contribute to children's development and learning skills. Intelligence behaviour and computer vision features in AI toys and robots affect some other functionalities, namely the functionality that can help children improve their socio-emotional and physical-motor development. The ability of toys and robots to act like humans (i.e. responding to questions and solving simple mathematical problems) can help children build bonding with the toys and robots. Additionally, the toys and robots' ability to detect and express emotion and present specific personalities help children to understand their surroundings. Some AI toys and robots provide additional accessories (known as components) to enhance children's experience. This specific element in AI toys and robots might amplify children's movement and physical activities. The findings offer a foundation for responsible innovation in the educational domain of IoT centred in AI for children, by informing context-aware, ethically aligned system design and reinforcing coherence with existing child-protection, data-governance, and educational policy frameworks.

The result of this study aims to examine three specific aspects of AI toys and robots. A study to explore the association of the multiple functionalities in AI toys and robots for children learning and development will be performed in the near future. Advanced digital play with AI toys and robots is in the early stage of its growing field (both in the entertainment and education industry, as well as in research). It is necessary to explore the advancement or newness of the AI system embedded in the toys and robots to consider their integration in early child education.

Adding to the early stage growing field context, a larger sample of AI toys and robots can be considered in future studies to improve the adequacy of the features and functionalities which are going to get more complex over time. Lastly, future studies should also include qualitative methods designed to explore perspectives from different stakeholders (i.e., educators, child-product designers, and children) to understand the implication of AI toys and robots for children's play experience.

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Comunicar, 86, XXXIV, 2026

## Appendix A: Observation Tool

### AI Toys or Robots Observation Guideline

Observer:
Toy/robot:
Company:
Language(s) of instruction:

This guideline is designed to observe and analyse the content, characteristic, and functionality of Artificial Intelligence (AI) Toys or Robots. Overall, it contains four parts.

1. General information
2. Physical characteristics of the toys or robots
3. AI features functionalities.
4. Children's developmental domains that are possibly affected by the interaction with AI toys or robotics.

### Instruction for the Analysis of Physical Toys

- Turn on the toy or robot.
- Read the guidance or user book if necessary.
- Check the overall physical components.
- Operate the toy or robot and navigate.
- Fill the form.

### Instruction for the Analysis from the Website

- Go to the official or merchant website of the toys.
- Check the description of the toys.
- Check the video description if it is available.

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## Part I: Physical Characteristics

*This section specifies the components aspect, colours and textures, dimensions and weight, & movement and gestures.*

| Components (Toy or robot has specific components) | Check the Box |
|---|---|
| • Switch buttons | |
| • Charger or battery | |
| • Cables connectors | |
| • Accessories to enhance play experience | |
| • Speaker(s) | |
| • Guidance or user book | |
| 1. It has a camera to capture or record video. | |
| 2. It has a microphone which is visible and easy to identify. | |
| **Colours and Textures** | **Check the Box** |
| 1. It has contrasting colours for different functionality (i.e. switches, connector, button, hole, and speaker). | |
| 2. It has different textures and materials for specific parts. | |
| **Dimension and weight** | **Check the Box** |
| 1. It is light enough for children in the age range 2 to 6 years to hold (with one hand or two hands). | |
| 2. Its size is suitable (not too big or too small) for children's toys of the age range 2 to 6 years. | |
| **Movement and Gestures** | **Check the Box** |
| 1. It moves within its surroundings. | |
| 2. It moves without moving around (i.e. dancing). | |
| 3. It has a remote control to navigate. | |
| 4. It has a digital application (for mobile or tablet) associated. | |
| 5. The switches and handles are easy to use (i.e. press, grasp, rotate, and fit) for children aged 2 to 6 years old. | |
| 6. It has the option of different speed modes (i.e. to make it slower or faster). | |

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## Part II: AI Functionalities

*This section specifies each specific feature of AI functionalities embedded in the toy or robot.*

| Data Processing (It can collect) | Check the Box |
|---|---|
| • Audio data | |
| • Visual data | |
| • Sensor data (i.e. fingerprint) | |
| **Intelligence Behaviour** | **Check the Box** |
| 1. It gives a human-like reaction to children´s voice (i.e. reacts to audio when a child talk to it). | |
| 2. It gives a human-like reaction to sensor data input (i.e. avoid the barrier when it bumps to another object). | |
| **Natural Language Processing** | **Check the Box** |
| 1. It can respond to questions given by children. | |
| 2. It has features in speech-to-text (i.e. show the transcription of what a child has said). | |
| **Personalized Learning** | **Check the Box** |
| 1. It can personalize learning contents based on collected data of the child. | |
| 2. It can personalize feedback. | |
| 3. It adapts to children´s knowledge level. | |
| 4. It suggests types of activities. | |
| 5. It can store and analyse children's learning performance. | |
| 6. It suggests a quiz or assessment. | |
| **Computer Vision** | **Check the Box** |
| 1. It has a feature to recognize object(s). | |
| 2. It has a feature to recognize children´s emotion(s). | |
| 3. It has a feature to recognize gesture (hand movement). | |
| 4. It has features to recognize body or object movement. | |

## Part III: Developmental Domains

*This section specifies children´s developmental domains (cognitive and language, socio-emotional, physical and motor, and general knowledge acquisition) that may be affected by the interaction with the AI toys/robots.*

| Cognitive and Language Developments | Check the Box |
|---|---|
| 1. It can teach children any level of literacy skills. | |
| 2. It can teach children any level of numeracy skills. | |
| 3. It can teach children any level of spatial thinking (direction and navigation). | |
| 4. It can teach children computational thinking (programming). | |
| 5. It can teach children any level of strategic thinking skills (i.e. teamwork and working toward goals). | |
| **Socio-Emotional Developments** | **Check the Box** |
| 1. It can teach children to identify different types of emotions (i.e. sad, happy, and excited). | |
| 2. It can teach children to regulate and express emotion. | |
| **Physical and Motor Developments** | **Check the Box** |
| 1. It can teach children physical or active play (i.e. robot produces songs, and it can dance or walk). | |
| 2. It can teach children´s fine motor skills (i.e. drawing or sketching). | |
| 3. It stimulates children´s gross motor skills (i.e. grasp and hold). | |
| 4. It stimulates children´s proprioception (the body´s ability to perceive its own position. It involves repetitive movements that the child can imitate by moving different parts of their body). | |
| **General Knowledge Acquisition** | **Check the Box** |
| 1. It gives children information about science. | |
| 2. It gives children information about humanities topics. | |
| 3. It can teach children artistic skills. | |
| 4. It can teach children skills related to music. | |
| 5. It can teach children skills related to storytelling. | |