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Review

Physical Robots in Education: A Systematic Review Based on the Technological Pedagogical Content Knowledge Framework

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Abstract: Driven by the wave of artificial intelligence, the educational practice and application of robots have become increasingly common. Despite extensive coverage in the literature on various aspects of educational robots, there are still unexplored avenues, particularly regarding robotic support, robotic personality, and challenges in their applications. This study presented a systematic review of high-quality empirical research on the use of physical robots in educational settings. A total of 92 relevant papers from the Web of Science database were analyzed. Employing the technological pedagogical content knowledge (TPCK) framework, we investigated research questions across seven components, including the learning domain, teaching strategy, robot types, learning results, problems with using robots, robotic support, and robotic personality. The findings revealed that robots are most prevalently employed in language learning applications. When opting for teaching strategies, educators tend to favor those that incorporate physical interaction. Concurrently, humanoid robots emerge as the preferred choice among many. These robots, in human–robot interaction scenarios, often exhibit an agreeable personality. In terms of evaluating learning results, cognitive aspects like thinking, creativity, self-regulation, and inquiry ability are especially emphasized. Such results are frequently influenced by the informational and emotional support provided by robots. Nonetheless, challenges encountered by teachers, learners, and robots in this process are not to be overlooked. The findings of this study contributed to future applications of robotics in education.

Keywords: physical robot; education; technological pedagogical content knowledge framework; robotic personality; robotic support; challenges

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1. Introduction

With the rise of artificial intelligence, there has been a growing prevalence in the use and integration of robots in educational settings [1]. The utilization of robots in education holds great potential for enhancing learners' social skills [2], critical thinking [3], computational thinking [4], and various other aspects [5]. Robots serve as a crucial tool for nurturing high-quality, interdisciplinary, and versatile talents, offering unparalleled educational value and promising development prospects [6]. Consequently, conducting thorough research on robots becomes imperative.

Moreover, the application of physical robots in education not only enhances various student capabilities but also significantly impacts sustainable development. By integrating robotic technology into education, the reliance on traditional educational resources, such as paper and physical teaching aids, can be markedly reduced, thereby decreasing resource consumption and environmental burden [7]. Concurrently, the use of robotic technology fosters the development of digital education, supports remote learning, and enables personalized education, all of which reduce commuting needs for students and teachers, thus lowering the carbon footprint [8]. Educational robots can also simulate real-world sustainable development practices, such as environmental monitoring and resource management, aiding students in better understanding and applying sustainability concepts [9]. Therefore, the application of robots in education not only improves educational quality but also advances sustainability in the educational sector.

A comprehensive systematic review on a specific topic can help researchers better understand the important research trends in one field [10,11]. Researchers have undertaken some comprehensive reviews of the existing research on the application of robots in the field of education. For example, Cheng and Sun [12] reviewed the basic applications of educational robots from the perspectives of experts, researchers, and teachers. The findings suggested that the five basic applications of educational robots are language education, robotics education, teaching assistance, social skill development, and special education. Xia and Zhong [13] reviewed the teaching content using K-12 robotics and highlighted the huge educational potential of educational robots in K-12 education. However, they also noted that there are cases where educational robots have not brought about significant improvements in students' learning. Woo and LeTendre's [14] review underscored the classroom application of social robots, suggesting that despite their innovative presence, these robots do not consistently outperform traditional human instruction or other technological tools. The review also sporadically touched upon pressing matters regarding ethics and safety linked to their use.

Previous scholarly reviews have conducted comprehensive explorations of various aspects related to educational robots, encompassing a wide range of elements such as geographical distribution, academic journal coverage, citation metrics, author contributions, keyword analysis, participant demographics, sample sizes, age groups, intervention durations, types of robots, robot roles, research methodologies, intervention strategies, measurement tools, learning domains, and pedagogical approaches [13–16]. Notwithstanding this broad research scope, there remain untapped avenues warranting closer scrutiny, notably the realms of robotic support, the personality of robots, and the challenges emerging from their application. Robotic support refers to the various functions and assistance that robots can provide in an educational context [17]. As suggested by Serholt [18], exploring the supports provided by robots can unravel how robots can be better programmed and utilized to support diverse learning objectives, bolstering the effectiveness of human–robot interaction and delivering a more rewarding and even personalized user experience. Additionally, another intriguing research opportunity is to investigate the personality traits of robots. Robots, with their capacity to emulate humanlike characteristics and behaviors, may engender unique emotional bonds with learners [19]. Understanding their personalities can assist in designing robots that are more relatable and effective [20]. Lastly, challenges are always an integral part of considering the characteristics of something new and emerging. As stated by Sharkey [21], evaluating the challenges encountered in robot usage can provide invaluable insights into practical issues, ethical considerations, and social implications that arise from integrating robots into learning environments.

In this regard, this paper lays emphasis on investigating the distinctive and consequential areas of robotic support, robot personalities, and the challenges encountered in their application. By delving into these under-researched areas, we aspire to contribute to generating a more nuanced understanding of educational robots, enhancing their integration and effectiveness in diverse learning contexts. Specifically, in the current study, based on the technological pedagogical content knowledge (TPCK) framework, we explore content knowledge (CK)—learning domain, pedagogical knowledge (PK)—teaching strategy, technological knowledge (TK)—robot types, technological content knowledge (TCK)—learning results, technological pedagogical knowledge (TPK)—problems with using robots, pedagogical content knowledge (PCK)—robotic support, and technological pedagogical content knowledge (TPCK)—robotic personality. Accordingly, we propose the following research questions:

RQ1: What learning domain has been adopted for the application of robots in educational teaching?
RQ2: What teaching strategy has been used in the application of robots in educational teaching?
RQ3: What robot types have been used in the application of robots in educational teaching?
RQ4: What learning results have been identified in the application of robots in educational teaching?
RQ5: What problems with using robots have been identified in the application of robots in educational teaching?
RQ6: What robotic support has been identified in the application of robots in educational teaching?
RQ7: What robotic personality has been used in the application of robots in educational teaching?

2. Research Methods

2.1. Literature Search

According to the recommendation by Zhang and Che [22], the WoS database, one of the most reliable and authoritative databases, was used in this study. Two sets of keywords were used for the data search: (1) robot-related words: "robot" or "robotic"; (2) education-related words "education" or "learning" or "teaching" or "teacher" or "student". The search was conducted on 28 August 2023—the cutoff date for published articles. By limiting the research areas to "Education Educational Research", the document types to "Article", and the languages to "English", a total of 699 articles were retrieved.

2.2. Data Selection

To identify empirical studies specifically addressing the implementation of robots in education, the search criteria were specifically tailored. As shown in Table 1, a set of inclusion and exclusion criteria were utilized for the research questions.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Research must use physical robots.	Research papers from conference proceedings, book chapters, magazines, news, and posters are excluded.
Research must report on the effectiveness of the robot in the actual teaching and learning process.	Incomplete studies were excluded, for example, studies that reported only on the development and design of robotic software or systems but not on empirical results.
Research must be published in peer reviewed journals.	Empirical research that merely used self-report data collections, such as interviews or surveys, is excluded.
Research must be reported as an empirical study to demonstrate the actual effectiveness of the robot in an educational setting.	Research on building robots in programming courses is not included.
Research must be reported in English.	Studies of faculty and student perceptions of robots were not included.
Full text is available.	

Two researchers independently screened the papers based on the predefined inclusion and exclusion criteria, resolving any discrepancies through discussion. Ultimately, a total of 92 publications that met the criteria were included in the final systematic review, as detailed in Table A1. Figure 1 represents the PRISMA flow diagram [23].

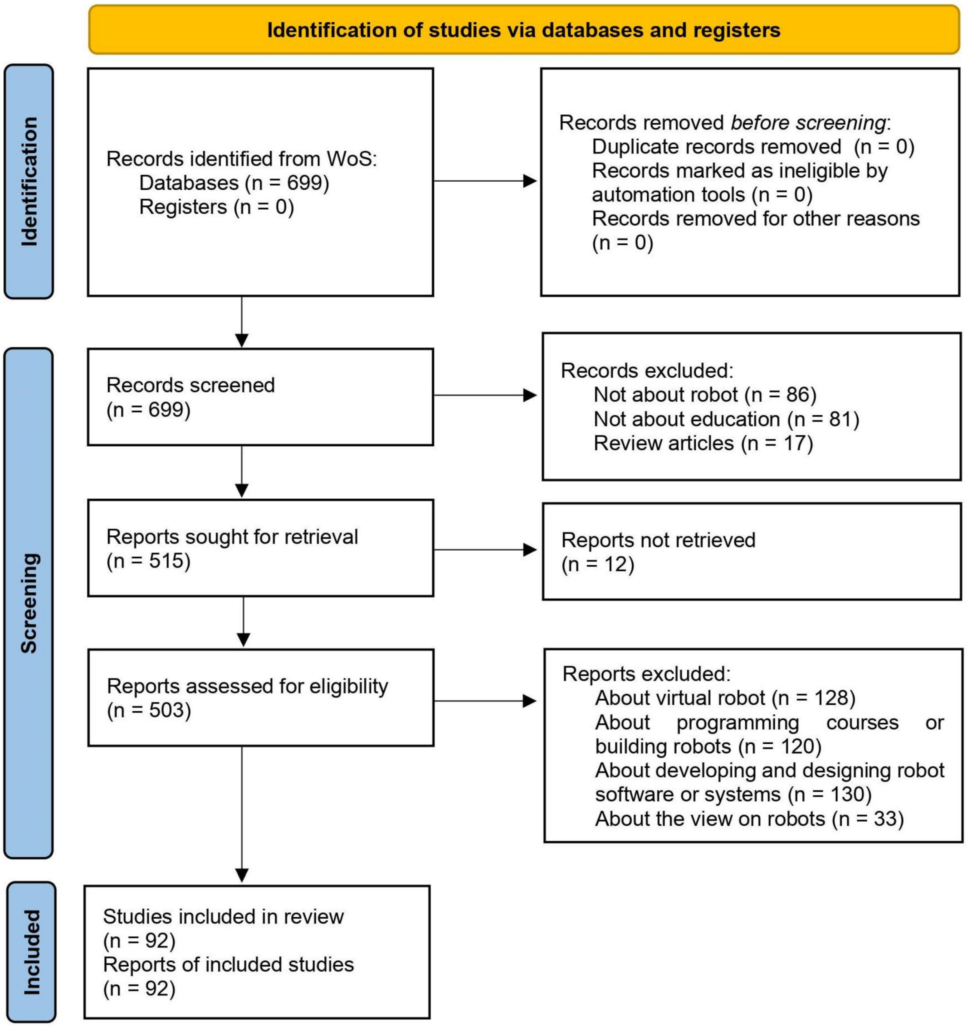

Figure 1. The PRISMA flow diagram.

2.3. Coding Schemes

The TPCK framework proposed by Mishra and Koehler [24] was adopted in this study (see Figure 2).

Table 2 shows the overall coding scheme of this study. As shown in Table 2, seven components were coded, including content knowledge (CK)—learning domain, pedagogical knowledge (PK)—teaching strategy, technological knowledge (TK)—robot types, technological content knowledge (TCK)—learning results, technological pedagogical knowledge (TPK)—problems with using robots, pedagogical content knowledge (PCK)—robotic support, and technological pedagogical content knowledge (TPCK)—robotic personality.

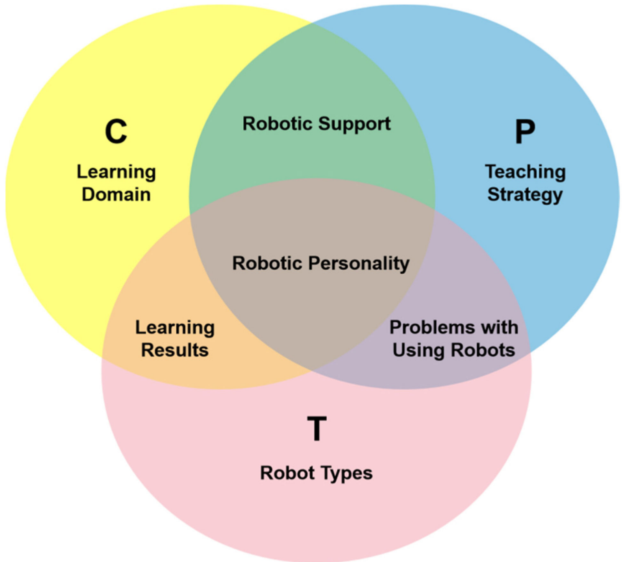

Figure 2. The TPCK framework and its knowledge components.

Table 2. Coding schemes.

Components	Dimensions	Coding Items	References
CK	Learning domain	Languages; engineering or computers; science; health, medical or nursing; social science or social studies; business and management; arts or design; mathematics	Hwang and Chang [16]
PK	Teaching strategy	Practice on specific learning material, physical interaction, communication, role play, and collaborative language learning	Engwall and Lopes [25]
TK	Robot types	Toy-like robots, face or belly screen robots, humanoid robots, robotic heads, and programmable robots	Engwall and Lopes [25]
TCK	Learning results	Cognitive, behavioral, and affective	Albarracin, Hepler [26]
TPK	Problems with using robots	Analyze the problem from 3 perspectives: teacher, student, and robot.	Huang, Hew [27]
PCK	Robotic support	Information support, information support, and emotional support	Leite, Castellano [28]
TPCK	Robotic personality	Openness, conscientiousness, extroversion, agreeableness, and neuroticism	Diener and Lucas [29]

3. Results

3.1. Content Knowledge—Learning Domain

Robotic classroom teaching activities have been widely applied in various learning domains [30]. We adopted a classification scheme that encompasses the following domains: languages, engineering or computing, sciences (including physics, chemistry, biology, environmental sciences, agriculture and industry), health, medicine or nursing, social sciences or social studies, business and management, art or design, and mathematics. This classification scheme is based on the findings of Hwang and Chang [16], where traditionally research has typically classified areas of study based on discipline-specific criteria. We chose this classification scheme because of its ability to provide comprehensive coverage of different disciplines and its high representativeness and applicability in research on educational robotic applications.

Figure 3 illustrates the distribution of learning domains in educational robotics, with languages being the predominant domain, represented in 37 articles. Engineering or computers and science domains are equally represented with 13 articles each. Social sciences also appear in 13 articles, while health, medical, or nursing domains are covered in 7 articles. Arts or design is the focus of four articles, mathematics in two, and there are three articles where the learning domain was not specified. Notably, there are no articles addressing business and management in this context.

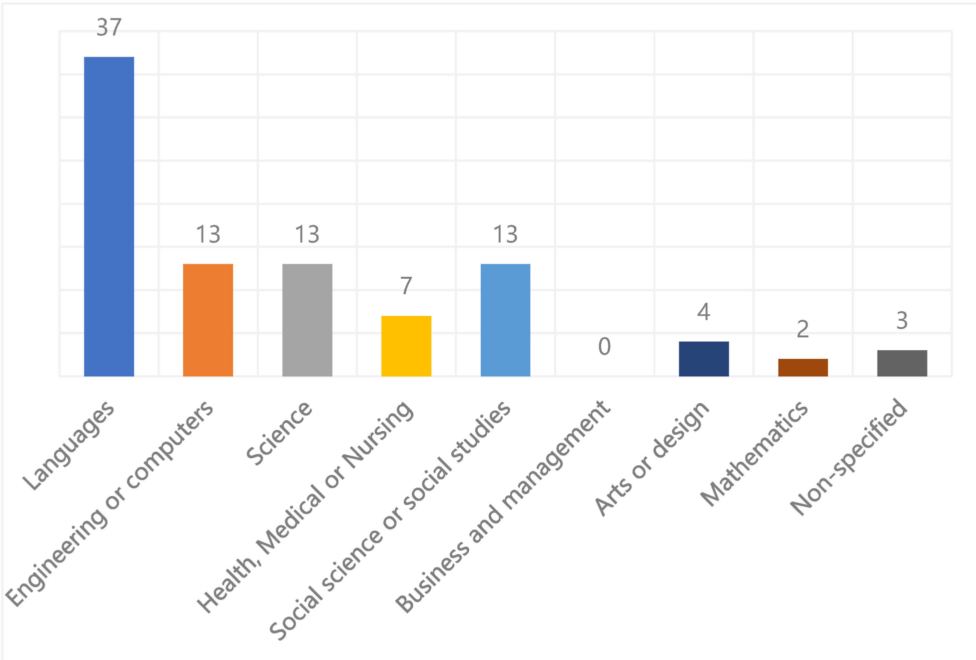

Figure 3. Distribution of learning domains.

3.2. Pedagogical Knowledge—Teaching Strategy

In educational practice, teaching strategy is often designed based on the course content and is a strategy built based on robot characteristics [31]. In line with Engwall and Lopes [25], the current study classified teaching strategies into five categories: practice on specific learning material, physical interaction, communication, role play, and collaborative language learning (CLL). Practice on specific learning material is the practice of using specific learning material through multimedia education or audio–verbal methods. Physical interaction refers to the display of physical gestures to the learner or allowing the learner to control or instruct through verbal commands. Communication is a robot asking and answering questions, over-structured conversational practice, and more free-flowing conversations. Role play is the construction of social relationships between robot and learner in specific scenarios. CLL is collaborative language learning among learners or between learners and robots.

In Figure 4, physical interaction (31 articles) is the most commonly used teaching strategy, followed by communication (22 articles), practice on specific learning material (15 articles), CLL (13 articles), and role play (11 articles).

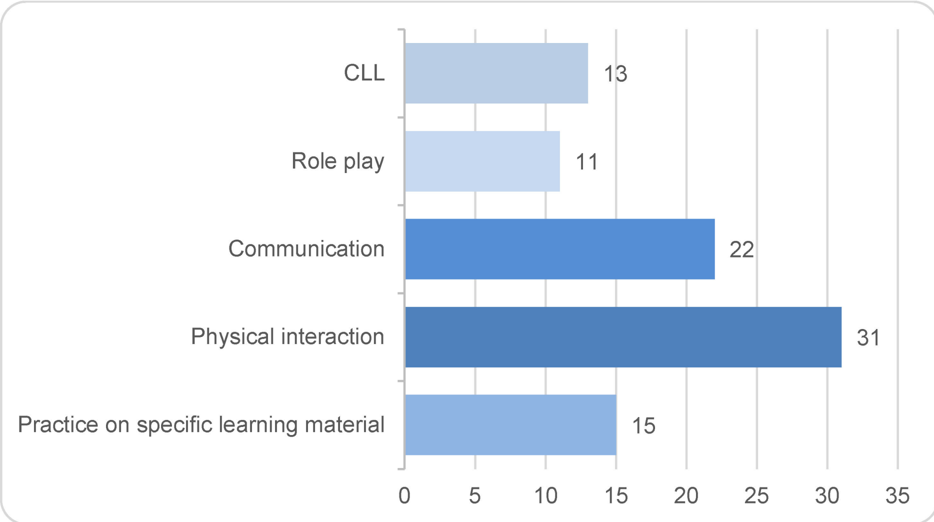

Figure 4. Distribution of teaching strategy.

3.3. Technological Knowledge—Robot Types

Engwall and Lopes [25] classified robot types into five categories based on the common characteristics of different robots used in educational research: toy-like robots, face or belly screen robots, humanoid robots, robotic heads, and programmable robots. Toy-like robots such as Lego Mindstorm, Tega, and iCat have familiar appearances and behaviors to children; thus, they pose no threat. Face or belly screen robots (such as PET, IROBI, EngKey, and Robosem) not only present learning materials on their screens but also establish contextual interactions through limited facial signals and body gestures, expanding multimedia-based exercises on the screen. Humanoid robots, such as Robosapien, Robovie, Mec Willy, and Nao, use the physical body of the robot to integrate more delicate arm and leg movements or interactions based on human-like gestures in practice. Robotic heads (such as Mero and Furhat) focus on the importance of facial signals in communication, such as the movements of the lips, eyes, and eyebrows to indicate attention and emotions, and on language learning, such as lip movements used for pronunciation training. Programmable robots are typically used in programming-related courses, and they are a manifestation of learners' creativity, obeying learners' commands and being more compliant.

As shown in Figure 5, humanoid robots (31 articles) are the most widely used robots, especially the NAO robot. Programmable robots (25 articles), face or belly screen robots (21 articles), toy-like robots (12 articles), and robotic heads (3 articles) have also been widely used in previous studies.

3.4. Technological Content Knowledge—Learning Results

According to Albarracin and Hepler [26], the learning outcomes can be divided into three aspects: cognitive, behavioral, and affective learning outcomes. At the cognitive level, learning results are manifested in knowledge and skills, mainly in areas such as thinking, creativity, self-regulation, and exploratory ability. At the behavioral level, learning results mainly refer to the actual behaviors that occur, including completion of the curriculum, level of learner participation, and learner achievement. At the affective level, learning results mainly reflect the learner's learning motivation, values, satisfaction, attitudes, experiential perception, and emotional outcomes.

As shown in Figure 6, in the sample of 92 articles, cognitive, behavioral, and affective appeared a total of 141 times. This means that in each study, two or three types of learning outcomes were evaluated. The study found that cognitive (40%) was the most frequently mentioned category, followed by behavioral (38%) and affective (22%).

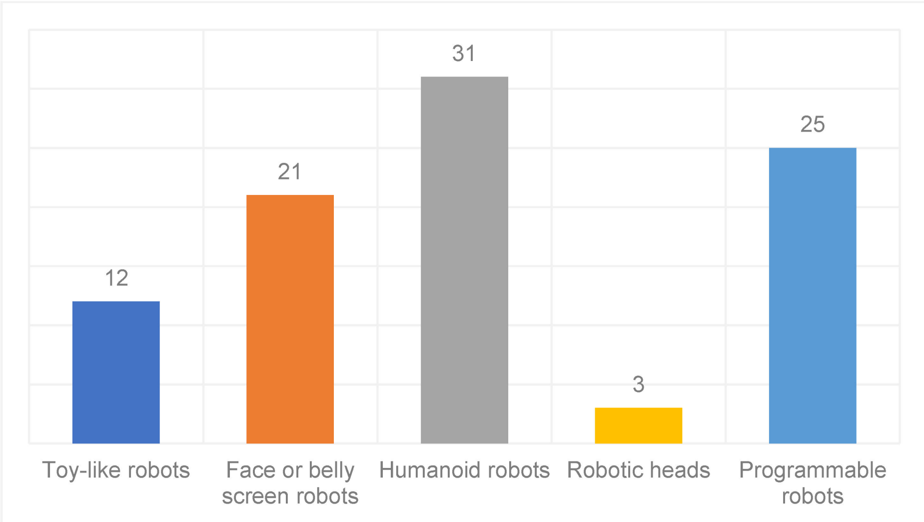

Figure 5. Distribution of robot types.

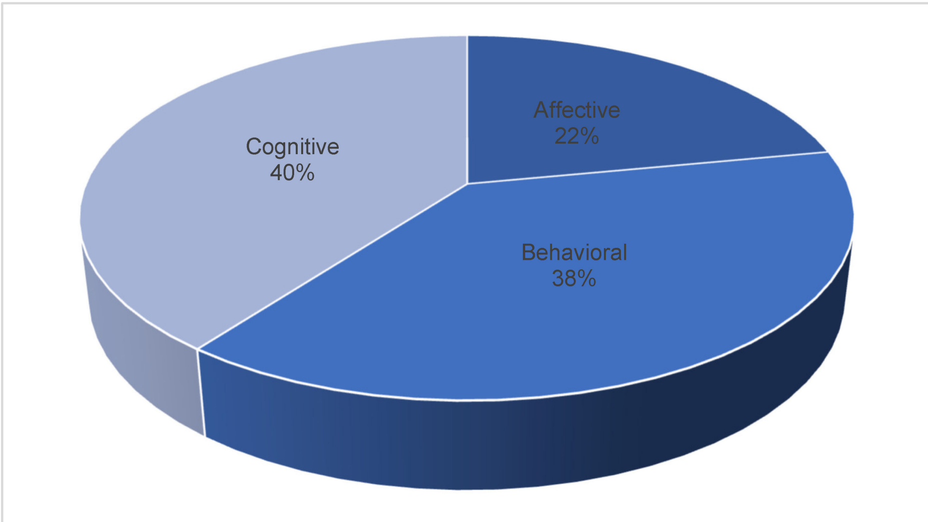

Figure 6. Distribution of learning results.

3.5. Technological Pedagogical Knowledge—Problems with Using Robots

Although using robots in an educational context has gradually matured, there are still many issues cannot be ignored [27]. This study analyzed the following problems from three perspectives: teachers, learners, and robots.

For teachers, there are challenges in standardizing the operation and use of robots, as well as a lack of relevant professional knowledge and technical support [32–35]. For the use of robots in classroom teaching, how to apply suitable teaching strategies and methods and designs for challenging teaching activities are important issues for teachers, which may increase their workload and teaching difficulties to some extent [33,36,37].

For learners, the novelty effect is always significant [38,39]. During the interaction, students' attention may be distracted by the gestures and actions of the robot, or by the teaching assistant controlling the robot in the classroom [33,40]. If the interaction time between learners and robots is short, learners cannot achieve deeper interactions [41]. Younger learners may have difficulty following the speech rate of robots, which may increase their comprehension difficulty unintentionally [42]. Younger learners are prone to emotional attachment to robots [43], while older learners have fewer opportunities to interact with robots and may not fully utilize their potential [41]. Learners are concerned about the safety of robots and fear that they may cause damage or explode [44].

For robots, on the one hand, robots have insufficient precision in their movements [33], a limited voice range [33], simplistic language [37], imperfect language recognition systems [42], and a non-emotional expression [33]. They are also prone to damage [33,37] and are expensive [32,33]. Additionally, the use of robots places a high demand on the environment, as robots have difficulty recognizing sound in noisy environments [33] and are susceptible to the effects of noise [34]. Moreover, robots have limited capacity for the autonomous adaptive learning of content [45] and recognizing [46] and managing [44] learners' behavior. On the other hand, robots provide little stimulation to learners and are difficult to sustain [33]. Human–machine interaction cannot reflect high complexity, differentiation, and flexibility [47]. Robots lack human emotions and empathy [44], and their emotions can be deceitful, resulting in a false relationship between a robot and teachers or learners [48].

3.6. Pedagogical Content Knowledge—Robotic Support

When interacting with students, the robot provides not only academic support (i.e., information support) but also emotional support [28]. In this study, emotional support refers to the advice or guidance provided by robots, as well as tangible assistance through the provision of goods or services. It also involves respecting and supporting learners, reinforcing their feelings, and expressing care or attachment towards them, as described by Leite and Castellano [28].

As shown in Figure 7, the robot was always able to provide informational support to the learner, as 38% of the educational activities demonstrated only informational support from the robot. Interestingly, in 62% of the educational activities, the robot provided both information and emotional support to the learner.

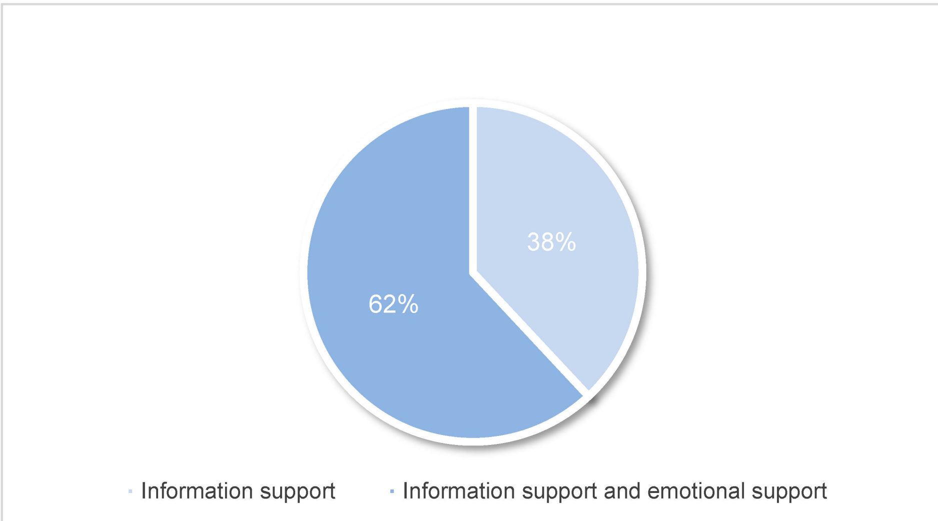

Figure 7. Distribution of robotic support.

3.7. Technological Pedagogical Content Knowledge—Robotic Personality

Humanoid robots have been a hot topic of research in the field of robotics [49–53]. In addition to being more human-like in appearance, robots have been emphasized to have different personalities [54]. Based on the big five personality (OCEAN) proposed by Diener and Lucas [29], the current study classified robots' personalities. Openness mainly reflects emotional richness and intelligence. Conscientiousness shows fairness and caution. Extroversion shows social and active traits. Agreeableness has trusting and dependent traits. Neuroticism shows repressed emotions.

As shown in Figure 8, in educational activities, robots tend to exhibit more agreeableness (38 articles) in their character traits, followed by extroversion (33 articles), conscientiousness (12 articles), openness (5 articles), and neuroticism (4 articles). It should be noted that robots with neuroticism personality have a more mechanical voice and show a cold expression.

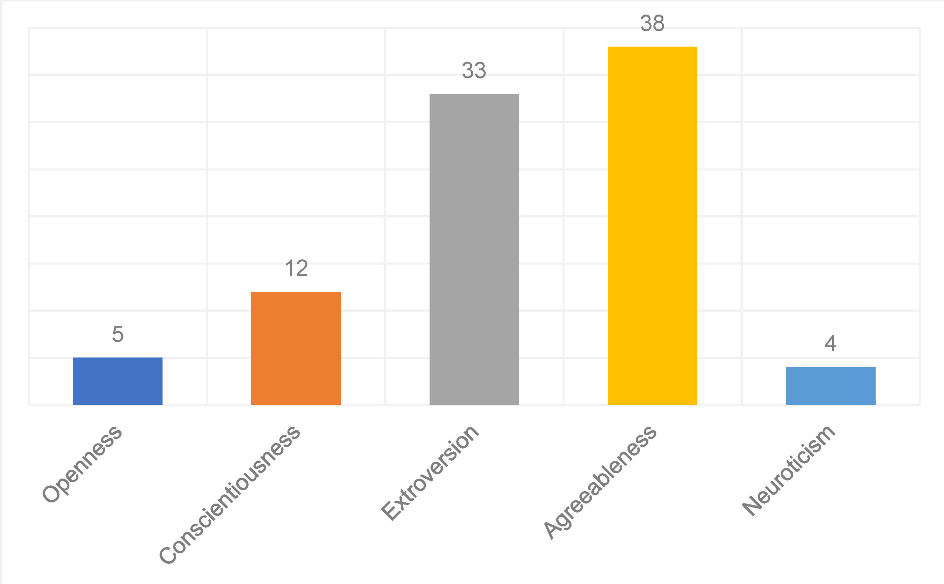

Figure 8. Distribution of robotic personality.

4. Discussion

Considering the importance of robots for teaching and learning, this article presents a systematic review of 92 empirical studies of physical robots based on the TPCK framework. In this section, we provide an in-depth analysis based on the conclusions drawn in this research and provide insights and suggestions for future research and applications of robots in the field of education.

4.1. Content Knowledge—Learning Domain

In terms of learning domains, a substantial amount of research has focused on language (37 articles) and science (13 articles), indicating a strong interest in these areas. However, the arts (4 articles) and health (7 articles) domains have been significantly underrepresented. One potential reason for this disparity could be the limited technological familiarity among learners and educators in these less-represented domains [55]. Our findings align with those of Hwang and Xie [56], who emphasize the critical need to integrate AI and technology into the development of educational robotic systems, especially in these underrepresented areas.

Considering these insights, we propose several implications for future research and practice. First, there is a clear and urgent need to broaden the integration of robotics in disciplines traditionally overlooked, such as the arts and health. Second, to address the observed limited technological experience in these fields, it is crucial to establish capacity-building programs that enhance the familiarity of both educators and students with robotic technologies [57]. By broadening our understanding and utilization of robotics across a wider spectrum of learning domains, we can fully leverage the educational benefits of robotics.

Furthermore, the inclusion of significant industrial and agricultural sectors in this study aligns with the journal's focus on sustainability and sustainable development. For example, integrating robotics and AI in agriculture can significantly enhance sustainability by optimizing resource usage and improving crop yields. This is supported by recent studies such as those by Loukatos and Kondoyanni [58], who explore the potential of electronics and AI in promoting sustainable agricultural practices. Therefore, it is essential for future research to consider these sectors to provide a comprehensive understanding of the impact of robotics across different industries, including those crucial for sustainable development.

By expanding the focus to include critical sectors such as agriculture and industry, we can ensure that the deployment of robotics and AI contributes to broader sustainability goals. This approach not only enhances the relevance of the research but also aligns with the journal's emphasis on sustainability and sustainable development.

4.2. Pedagogical Knowledge—Teaching Strategy

In the context of teaching strategies, our research findings reveal a predominance of physical interaction, followed by communication. This prevalence of physical interaction mirrors the practical application of robots in education, where interaction with learners—whether physical or verbal—forms the crux of most teaching strategies [59]. However, our findings diverge from those of Alimisis [60], who emphasizes the equal importance of both physical and verbal communication in educational robotics. This discrepancy may be attributed to different research contexts and methodological variations, warranting further investigation. Furthermore, our study observed a mismatch between the robots used and the teaching strategies employed in many studies. This observation echoes the concerns raised by Alimisis [60] about the need for congruence between the robots' capabilities and the educational goals of the teaching strategy. This mismatch presents an avenue for future research to consider when designing empirical studies in educational robotics. Lastly, the role play teaching strategy was found to have the least representation in our study. This observation seems to be linked to role play's prevalence in the artistic field [61]. Given that our research sample exhibited a low proportion of studies focusing on the artistic field, this naturally led to a decreased occurrence of role play.

Considering these findings, we recommend future researchers to ensure alignment between the robots' features and the teaching strategy employed. We also suggest a deeper exploration of less-used teaching strategies like role play in other educational domains beyond the arts. Further, investigating the impacts of varied teaching strategies on learners' engagement and learning outcomes could provide valuable insights for the effective integration of robots in education.

4.3. Technological Knowledge—Robot Types

The integration of robots in educational settings can be understood through different intelligence levels. Huang and Rust [62] delineate three intelligence levels within service contexts: mechanical, thinking, and feeling. They advocate for the integration of robots/AI at the mechanical and thinking strata while preserving the feeling dimension for human intervention.

Humanoid robots, particularly the NAO robot, are the most prevalent in educational settings. These robots possess advanced capabilities in flexibility, intelligence, interaction, and the display of emotions, as noted by Robaczewski and Bouchard [63]. The preference for humanoid robots might be attributed to several factors. Humanoid robots are easier to bring closer to students and increase the realism of interaction because of their similar appearance to humans [64]. Moreover, humanoid robots can take on different roles, enhancing the immersive learning experience and increasing the educational gain [65]. These findings align with studies such as that conducted by Mubin and Stevens [66], which advocates for humanoid robots' effectiveness in promoting engagement and learning. Second in line are programmable robots. Echoing Castro and Cecchi [67], these robots, through visual programming, foster problem-solving skills, bridging the gap between abstract concepts and tangible real-world applications. However, as denoted by Alimisis [60], more research is needed to optimize programmable robots' pedagogical strategies and integrate them seamlessly into diverse educational contexts. Robotic heads are least employed, possibly due to their unconventional appearance, which may impart an oppressive sensation to learners, as observed by Robert [68]. This is in contrast with the study by Fong and

Nourbakhsh [69], which found robotic heads to be a powerful tool for social interaction and empathy-building.

Understanding these levels helps in categorizing and deploying educational robots effectively, ensuring that their capabilities are utilized appropriately within the educational context [62]. In light of these findings, we suggest future research to continue exploring how different types of robots can be effectively utilized and adapted to various educational contexts.

4.4. Technological Content Knowledge—Learning Results

The results of our analysis highlight cognitive outcomes as the dominant evaluative metric in robotics education research, suggesting that traditional knowledge and skill acquisition goals persist as a primary focus. Our result is in line with Sullivan and Bers [70]. Behavioral outcomes, while trailing slightly behind cognitive ones, represent a significant portion of the evaluation landscape. This emphasis on observable behaviors underscores the growing recognition of robots' potential for enhancing practical skill development in learners [71]. This suggests a promising shift towards a more holistic, competence-based evaluation approach, bridging theory and practice. However, it also spotlights the challenge of developing reliable, objective measures for such outcomes, warranting further research in this area. Affective outcomes constitute a smaller proportion of the evaluation parameters. This discrepancy could partly stem from the inherent difficulty of quantifying and measuring these outcomes, a perennial challenge in education evaluation [72]. But the use of AI in dynamic educational evaluation is also gradually changing the limitations of traditional evaluation [73,74]. This lays the foundation for the future use of robots for diverse educational assessments.

Our research underscores the need for a more nuanced, comprehensive evaluation framework in robotics education, encompassing cognitive, behavioral, and affective outcomes. Moving forward, it would be beneficial to establish more sophisticated methods for capturing and assessing affective outcomes, an under-researched area with the potential to enhance the holistic development of learners. Further, research could explore how different types of robots, teaching strategies, and contexts influence these three dimensions of learning outcomes.

4.5. Technological Pedagogical Knowledge—Problems with Using Robots

The challenges regarding the use of robots in education are multifaceted. They are not simply a matter of technology but are closely related to the way teachers and learners use and perceive technology. In addition to improving the technologies, issues rooted in the current state of robotics should be mitigated to some extent by the proficiency of teachers [60]. As guides and interpreters of robotic functionality, teachers should improve their AI readiness and competence through continuous learning [75]. For example, through learning, teachers are able to swiftly identify and rectify any inaccuracies or deficiencies in robots' instructional delivery [76]. Additionally, they are expected to provide learners with necessary explanations and assurances, fostering a sense of security [77].

Concerning the novelty effect, we propose conducting preliminary workshops before the formal introduction of robots in classrooms [76]. These sessions can acclimate learners to the concept and practice of robotics, thereby easing their transition into a new learning environment. Considering the potential of robotics in education, future research should propose further measures to reduce its potential problems to maximize the advantages of robotics.

Furthermore, within the framework of service relationships, Reis [78] reveals various relational tiers, positioning educational services at level 2—human–robot teams. Herein, robots in educational teaching potentially operate within a human–bot symbiotic paradigm. Understanding these technical issues might be relevant for assessing machine capabilities and aligning them with the existing literature. Introducing this discussion enhances the understanding of how robots can be effectively utilized in educational contexts and highlights the importance of a balanced human–robot collaboration to maximize educational outcomes [78].

By addressing these challenges and leveraging the strengths of both humans and robots, we can create a more effective and harmonious educational environment. Future research should continue to explore strategies to integrate robots into educational settings seamlessly, ensuring that their use complements and enhances traditional teaching methods rather than replacing the human element that is crucial for empathetic and intuitive interactions [62].

4.6. Pedagogical Content Knowledge—Robotic Support

Analyzing the facet of robotic support reveals the role of robots in educational activities. Our research underscores the emerging preference among learners for emotionally supportive behaviors (such as demonstrating respect and care) from robots, as opposed to simply providing tangible assistance or factual information [79]. When it comes to human teachers, there is an expectation that teachers should not only impart knowledge but also provide emotional support for their students [80]. As stated by Leite and Castellano [28], it appears that the interpersonal dynamics often associated with human–human interactions are being projected onto, and expected from, human–robot interactions. This is a novel finding that reinforces the evolution of robots as social interactive agents, and the potential implications for their deployment in educational settings.

This finding raises several new questions for future research. For instance, what factors influence the perceived efficacy of emotional support from robots? Are there specific contexts or domains where emotional support from robots is particularly beneficial, or perhaps detrimental? How can the design and programming of educational robots be optimized to provide effective emotional support while also delivering their core instructional functions? Investigating these questions could offer valuable insights for enhancing the impact of robots in education, paving the way for the next generation of human–robot interaction in learning environments.

4.7. Technological Pedagogical Content Knowledge—Robotic Personality

Our study finds a predominance of the trait of agreeableness. Robots often comply with learners' directives to meet instructional objectives [81]. Trust, a cornerstone of robot–learner interaction, seems to explain this trend. Furthermore, extroverted personalities are also frequently observed in humanoid robots. The inherent social and active nature fosters more interactive and engaging human–robot interactions [82]. On the contrary, the traits of openness and neuroticism appear to be less prevalent in robots. The requirement for a high degree of sophistication to embody openness might explain its rarity. In our study, only NAO robots were identified with this trait, signifying the advanced capabilities of this specific robot type. As for neuroticism, its low occurrence can be attributed to the infrequent creation of hostile environments in educational settings. It is highly uncommon for robots to demonstrate adversarial behaviors towards learners [83].

Our research underlines the critical role of robotic personality traits in educational settings, a somewhat neglected yet promising research area. As we move forward, the development of robots that embody a balanced mix of personality traits could be instrumental in enhancing learning experiences. Future research should also investigate the impact of different robotic personalities on student engagement, motivation, and academic performance.

5. Conclusions

This study provides a systematic review of 92 high-quality empirical research articles on the use of physical robots in educational settings. Based on the TPCK framework, we conclude the following findings:

5.1. Contributions to the Literature

Our review reveals that the majority of the 92 papers reviewed predominantly focus on language instruction. This indicates a significant interest in utilizing robots to enhance language learning, aligning with the growing emphasis on developing communication skills in education. Additionally, there is a clear preference among researchers for humanoid robots, particularly the NAO robot. These robots are favored due to their advanced capabilities in interaction and emotional expression, making them effective tools for engaging students.

5.2. Practical Contributions

From a practical standpoint, educators tend to favor teaching strategies that involve physical interaction during instructional activities. This approach not only makes learning more engaging but also aids in the better retention of information. Robots typically display compliant attitudes and agreeable personalities, which contribute to creating a positive learning environment. With respect to learning outcomes, cognitive outcomes are the predominant learning outcomes. These outcomes are significantly enhanced by the informational and emotional support provided by the robots.

5.3. Limitations and Further Research Endeavors

Although this article provides insight into the research and application of physical robots in education, there are still some limitations that should be addressed in future studies. Firstly, this study only considered relevant articles published in the WoS database. Future studies should further consider articles from different academic databases (such as Scopus) and papers presented at renowned conferences. According to the findings of Ewald and Klerings [84], including multiple databases in the search process can significantly reduce the risk of omitting pertinent studies. Expanding the scope of our search in future research would enhance the comprehensiveness and robustness of the literature review. Secondly, the analytical results of this study are highly dependent on the classification and coding scheme. Therefore, future studies have the potential to analyze articles on the application of robots in education from different analytical perspectives and using different analytical methods. Third, from a systematic perspective, we employed the TPCK framework to code various intricate elements, but the interactions between these elements have been only superficially examined. Therefore, it is necessary to further explore the complex relationships between different elements.

5.4. Implications of the Findings

Our findings suggest several implications for both researchers and practitioners. For researchers, the emphasis on language instruction and humanoid robots opens up avenues for exploring other subjects and robot forms. For practitioners, the positive impacts of physical interaction and compliant robot personalities underline the importance of designing robots that can effectively engage and support students emotionally and cognitively.

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Appendix A

Table A1. Table of analyzed literature sources.

Article	Learning Domain	Learning Results	Robot Types	Robotic Support	Robotic Personality	Teaching Strategy
Engwall and Lopes [25]	Languages	Behavioral	Robotic heads	Information support	Extraversion	Communication
Fridin [44]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Openness	Communication
Hughes-Roberts, Brown [85]	Health, Medical or Nursing	Behavioral	Humanoid robots	Information support	Conscientiousness	Communication
Wu, Wang [86]	Languages	Affective, behavioral, cognitive	Face or belly screen robots	Information support and emotional support	Extraversion	Physical interaction
Özdemir and Karaman [87]	Health, Medical or Nursing	Behavioral	Humanoid robots	Information support and emotional support	Extraversion	Physical interaction
Banaeian and Gilanlioglu [43]	Languages	Affective, behavioral	Humanoid robots	Information support and emotional support	Extraversion	CLL
Yang, Luo [88]	Engineering or computers	Affective, behavioral, cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Noh and Lee [89]	Science	Cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Hong, Huang [90]	Languages	Affective, cognitive	Programmable robots	Information support	Agreeableness	CLL
Lei, Clemente [47]	Social science or social studies	Behavioral	Face or belly screen robots	Information support	Neuroticism	Communication
Engwall, Lopes [91]	Languages	Affective	Robotic heads	Information support and emotional support	Extraversion	Communication
Al Hakim, Yang [92]	Languages	Affective, behavioral	Face or belly screen robots	Information support and emotional support	Extraversion	Role play
Velentza, Fachantidis [93]	Science	Behavioral	Humanoid robots	Information support and emotional support	Agreeableness	Communication
Kewalramani, Kidman [94]	Science	Affective, behavioral, cognitive	Toy-like robots	Information support and emotional support	Agreeableness	Communication
Chen, Park [42]	Languages	Affective, behavioral	Toy-like robots	Information support and emotional support	Openness	Role play
Hung, Chao [37]	Languages	Affective	Face or belly screen robots	Information support and emotional support	Extraversion	Practice on specific learning material
Crompton, Gregory [35]	Social science or social studies	Affective, behavioral, cognitive	Humanoid robots	Information support and emotional support	Conscientiousness	Physical interaction
Chen Hsieh [95]	Languages	Affective, behavioral	Face or belly screen robots	Information support and emotional support	Neuroticism	Practice on specific learning material
Wei, Hung [46]	Mathematics	Affective, cognitive	Toy-like robots	Information support and emotional support	Conscientiousness	Communication
Alemi and Haeri [32]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Openness	Physical interaction
Chang, Lee [34]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Extraversion	Physical interaction
Mioduser, Levy [96]	Languages	Cognitive	Programmable robots	Information support	Agreeableness	Physical interaction

Table A1. *Cont.*

Article	Learning Domain	Learning Results	Robot Types	Robotic Support	Robotic Personality	Teaching Strategy
Iio, Maeda [97]	Languages	Cognitive	Face or belly screen robots	Information support and emotional support	Extraversion	Role play
Leeuwestein, Barking [39]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Extraversion	CLL
Sen, Ay [98]	Engineering or computers	Cognitive	Toy-like robots	Information support	Agreeableness	Practice on specific learning material
Keane, Chalmers [99]	Languages	Affective, behavioral	Humanoid robots	Information support and emotional support	Agreeableness	Communication
David, Costescu [100]	Health, Medical or Nursing	Cognitive	Humanoid robots	Information support	Extraversion	Physical interaction
Kewalramani, Palaiologou [36]	Social science or social studies	Affective, behavioral	Toy-like robots	Information support and emotional support	Extraversion	Role play
Mitnik, Nussbaum [101]	Science	Cognitive	Face or belly screen robots	Information support	Agreeableness	CLL
Resing, Bakker [48]	Social science or social studies	Cognitive	Toy-like robots	Information support and emotional support	Extraversion	Communication
Kim, Marx [102]	Non-specified	Behavioral	Toy-like robots	Information support and emotional support	Extraversion	Communication
Chen Hsieh and Lee [103]	Languages	Affective, behavioral, cognitive	Face or belly screen robots	Information support and emotional support	Neuroticism	Practice on specific learning material
Van den Berghe, de Haas [49]	Languages	Affective	Humanoid robots	Information support and emotional support	Conscientiousness	Practice on specific learning material
Nam, Kim [104]	Science	Cognitive	Programmable robots	Information support and emotional support	Agreeableness	Physical interaction
Merkouris, Chorianopoulou [105]	Science	Cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Han, Jo [65]	Arts or design	Affective, behavioral	Face or belly screen robots	Information support and emotional support	Extraversion	Practice on specific learning material
Konijn and Hoorn [106]	Science	Cognitive	Humanoid robots	Information support and emotional support	Extraversion	Communication
Valente, Caceffo [107]	Social science or social studies	Behavioral	Toy-like robots	Information support	Agreeableness	Role play
Yueh, Lin [40]	Languages	Behavioral	Face or belly screen robots	Information support and emotional support	Agreeableness	Practice on specific learning material
Evripidou, Amanatiadis [108]	Science	Affective, behavioral, cognitive	Programmable robots	Information support and emotional support	Agreeableness	Practice on specific learning material
Mazzoni and Benvenuti [109]	Languages	Behavioral, cognitive	Humanoid robots	Information support and emotional support	Openness	Physical interaction
Lee, Noh [110]	Languages	Affective, cognitive	Face or belly screen robots	Information support and emotional support	Openness	Role play
Kim and Tscholl [111]	Languages	Affective, behavioral, cognitive	Face or belly screen robots	Information support and emotional support	Extraversion	CLL
Shumway, Welch [112]	Mathematics	Behavioral, cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Liao and Lu [113]	Languages	Behavioral	Face or belly screen robots	Information support	Neuroticism	Communication
Hsiao, Chang [114]	Languages	Affective, behavioral, cognitive	Face or belly screen robots	Information support and emotional support	Extraversion	CLL

Table A1. *Cont.*

Article	Learning Domain	Learning Results	Robot Types	Robotic Support	Robotic Personality	Teaching Strategy
Çakır, Korkmaz [115]	Engineering or computers	Cognitive	Programmable robots	Information support and emotional support	Agreeableness	Physical interaction
Chernyak and Gary [116]	Social science or social studies	Affective, behavioral, cognitive	Toy-like robots	Information support and emotional support	Agreeableness	Physical interaction
Yang, Ng [117]	Science	Cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Resing, Vogelaar [118]	Science	Cognitive	Toy-like robots	Information support and emotional support	Extraversion	Physical interaction
Brainin, Shamir [119]	Engineering or computers	Cognitive	Programmable robots	Information support	Agreeableness	Practice on specific learning material
Neumann, Neumann [38]	Arts or design	Behavioral	Humanoid robots	Information support and emotional support	Extraversion	Physical interaction
Benvenuti and Mazzoni [120]	Social science or social studies	Cognitive	Humanoid robots	Information support and emotional support	Conscientiousness	Communication
Pop, Simut [121]	Social science or social studies	Cognitive	Face or belly screen robots	Information support and emotional support	Extraversion	Communication
Chevalier, Giang [122]	Engineering or computers	Cognitive	Programmable robots	Information support	Agreeableness	Communication
Chew and Chua [123]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Extraversion	CLL
Pérez-Marín, Hijón-Neira [124]	Social science or social studies	Behavioral, cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Bravo, Hurtado [125]	Arts or design	Affective, cognitive	Programmable robots	Information support	Agreeableness	Role play
Demir-Lira, Kanero [126]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Conscientiousness	CLL
Alemi and Bahramipour [127]	Languages	Behavioral, cognitive	Humanoid robots	Information support and emotional support	Extraversion	CLL
Cherniak, Lee [128]	Engineering or computers	Behavioral	Programmable robots	Information support	Agreeableness	Practice on specific learning material
Silva, Fonseca [129]	Engineering or computers	Cognitive	Programmable robots	Information support	Agreeableness	Practice on specific learning material
Arar, Belazoui [130]	Languages	Cognitive	Robotic heads	Information support and emotional support	Extraversion	CLL
Khalifa, Kato [131]	Languages	Behavioral, cognitive	Humanoid robots	Information support and emotional support	Conscientiousness	Communication
Hall and McCormick [132]	Science	Cognitive	Programmable robots	Information support and emotional support	Agreeableness	Physical interaction
Tolksdorf, Crawshaw [133]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Conscientiousness	CLL
Ferrarelli and Iocchi [134]	Science	Behavioral, cognitive	Face or belly screen robots	Information support	Agreeableness	Physical interaction
Ishino, Goto [41]	Social science or social studies	Cognitive	Humanoid robots	Information support	Agreeableness	Communication
Alhashmi, Mubin [45]	Non-specified	Affective	Humanoid robots	Information support and emotional support	Conscientiousness	Physical interaction
Welch, Shumway [135]	Engineering or computers	Cognitive	Programmable robots	Information support	Agreeableness	Physical interaction

Table A1. *Cont.*

Article	Learning Domain	Learning Results	Robot Types	Robotic Support	Robotic Personality	Teaching Strategy
Keller and John [136]	Engineering or computers	Affective	Humanoid robots	Information support and emotional support	Extraversion	Role play
Paucar-Curasma, Villalba-Condori [137]	Engineering or computers	Affective, cognitive	Programmable robots	Information support and emotional support	Agreeableness	Physical interaction
Urlings, Coppens [138]	Social science or social studies	Cognitive	Programmable robots	Information support and emotional support	Agreeableness	Practice on specific learning material
So, Wong [139]	Health, Medical or Nursing	Behavioral, cognitive	Humanoid robots	Information support	Extraversion	Role play
Liang and Hwang [140]	Languages	Behavioral	Face or belly screen robots	Information support	Agreeableness	Communication
Peura, Mutta [141]	Languages	Behavioral	Humanoid robots	Information support and emotional support	Conscientiousness	Practice on specific learning material
Veivo and Mutta [142]	Languages	Behavioral	Humanoid robots	Information support	Conscientiousness	Practice on specific learning material
Chung [143]	Arts or design	Behavioral, cognitive	Humanoid robots	Information support and emotional support	Extraversion	Physical interaction
Chang, Hwang [144]	Health, Medical or Nursing	Affective, behavioral	Face or belly screen robots	Information support and emotional support	Extraversion	Communication
Kalmpourtzis and Romero [145]	Social science or social studies	Behavioral, cognitive	Toy-like robots	Information support	Agreeableness	Physical interaction
Saadatzi, Pennington [146]	Languages	Cognitive	Humanoid robots	Information support	Agreeableness	Practice on specific learning material
Chiang, Cheng [147]	Languages	Cognitive	Face or belly screen robots	Information support	Conscientiousness	CLL
Cheng, Wang [148]	Languages	Behavioral, cognitive	Face or belly screen robots	Information support and emotional support	Extraversion	Role play
Sabena [149]	Science	Behavioral, cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Kwon, Jeon [150]	Engineering or computers	Cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Chen, Qiu [151]	Non-specified	Affective	Humanoid robots	Information support and emotional support	Extraversion	Communication
Hsieh, Yeh [152]	Languages	Affective, behavioral, cognitive	Face or belly screen robots	Information support and emotional support	Extraversion	CLL
Angeli and Georgiou [153]	Engineering or computers	Behavioral, cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Kim, Hwang [154]	Social science or social studies	Affective, behavioral	Toy-like robots	Information support and emotional support	Extraversion	Communication
Bargagna, Castro [155]	Health, Medical or Nursing	Behavioral, cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
Cervera, Diago [156]	Engineering or computers	Cognitive	Programmable robots	Information support	Agreeableness	Physical interaction
So, Cheng [157]	Health, Medical or Nursing	Affective, behavioral, cognitive	Humanoid robots	Information support and emotional support	Extraversion	Role play

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