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A Comprehensive Review on r-Learning: Authentic r-Learning Beyond the Fad of New Educational Technology

Sung Eun Jung[1], Jeonghye Han[2†]

[1]*Assistant Professor of Practice , Department of Teaching, Learning, and Sociocultural Studies, The University of Arizona, U.S, sungeun@email.arizona.edu,*
[2]*Professor, Department of Computer Education, Cheong Ju National University of Education, South Korea, †hanjh@cje.ac.kr*

Abstract

We conducted a comprehensive review on the previous research on r-Learning. By reviewing 843 previous studies about r-Learning published from 2004 to 2015, this study investigated 1) the trend of research on r-Learning over time, 2) the characteristics of targeted students in r-Learning, 3) the educational activities implemented for r-Learning, and 4) the types of educational robots used for r-Learning. The study found that the research on r-Learning has rapidly and steadily increased and the types of educational activities and educational robots has been diversified. Relying on the findings of this review, this study suggests 1) ensuring growth in both the quality and the quantity of research on r-Learning, 2) broadening the target student population of r-Learning beyond the age-limited boundaries, 3) enhancing educational activities of r-Learning, and 4) recognizing the necessity for systematic and clear concepts of types of educational robots.

Key words*: r-Learning, Robotics Education, Educational Robots, Robot-assisted Learning, Programming, Engineering Practice*

1. INTRODUCTION

It can be said that the educational service robot is equipped with a service for educational purposes [1]. In this study, r-Learning refers to learning that involves different types of educational robots. Goodrich and Schultz categorized robots for education as assistive robots and educational robots [2]. Han classified robots as hands-on robots for STEM (Science, Technology, Engineering and Mathematics) education with educational robots and educational service robots with assistive robots [3]. Referring to these categories, she defined r-Learning as learning that uses educational and assistive robots. Park and Han developed Han's concept of hands-on robots further and defined hands-on robots as user-buildable robots [4]. In the same research, they defined convertible robots as robots that were not originally created for education but were used for teaching and learning, and they identified how the user-buildable robots and convertible robots were employed in the current studies of r-

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Corresponding Author: hanjh@cje.ac.kr
Tel: +82-43-299-0853
Professor, Department of Computer Education, Cheong Nam-ro 2065, Cheonju, Chungbuk, Republic of Korea, 28690

Learning.

The distinct features and benefits of r-Learning have been gaining attention in relation to STEM teaching and learning at all levels [5]. Educational robots are considered effective tools to motivate students to learn STEM. Students' interaction with the educational robots is perceived as effective involvement with STEM-related skills, concept. Also, robotics itself has an interdisciplinary nature similar to STEM. Based on the premise that students' engagement in r-Learning shares common features with STEM education (e.g., application of the engineering design process, a real context-based problem-solving activity, teamwork, and an interdisciplinary approach) [6], r-Learning itself functions as an academic discipline that students need to learn [7].

Also, educational robots are considered to be a technological environment. In this case, educational robots – educational service robots – can serve and assist student's learning and teachers' teaching [8]. The rapid changes and innovation in technological environments are understood as social and cultural changes in the lives of students who are digital natives [9]. Interactive technology-enriched environments are assumed to transform students' ways of thinking, communicating with others, making decisions, and living. In this context, r-Learning involves different types of educational robots as interactive environments in addition to other educational media (e.g., apps, software programs, digital materials, e-books, and websites), in order to better support young children in growing up as competent and capable individuals in their changing technological environments. R-Learning can provide students with educationally appropriate opportunities for gaining knowledge about new types of technology [10]

In the following sections, first, we will describe the procedure of the comprehensive review process. Next, we will present the synthesized results of the relevant studies guided by the research questions. Then, we will discuss the directions for future research on r-Learning by addressing the strengths and limitations of the existing studies.

2. METHODS

2.1 LITERATURE SELECTION PROCESS

It is obvious that r-Learning has the power to attract the attention of students' of all ages, and researchers and educators recognize its impact [11]. This claim has been generated and reproduced through studies and educational programs; that is, r-Learning is effective for students' learning in different subject areas including STEM and teachers' teaching and other tasks. However, a repeated criticism is that there is a lack of comprehensive and critical perspectives on r-Learning [12]. Thus, a rigorous review of previous studies of r-Learning is worthwhile in order to identify gaps in the research, find new directions for future research, and share the knowledge with the r-Learning community. To do this, we thoroughly reviewed the research articles on r-Learning published from 2004 to 2015. The following key research questions guided this study:

Q1. What was the trend of research on r-learning change over the decade?
Q2. Who were the targeted students in the previous literature?
Q3. What educational activities were implemented for r-Learning in the previous literature?
Q4. What types of educational robots were employed for r-Learning in the previous literature?

We employed the systematic review process developed and suggested by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for conducting a reliable and comprehensive literature review research [13] (see Figure 1). We used the following seven international databases: ACM Digital Library, ERIC (Educational Resources Information Center), Google Scholar, IEEE XPLORE, ScienceDirect, Springer Link, and Wilson Education.

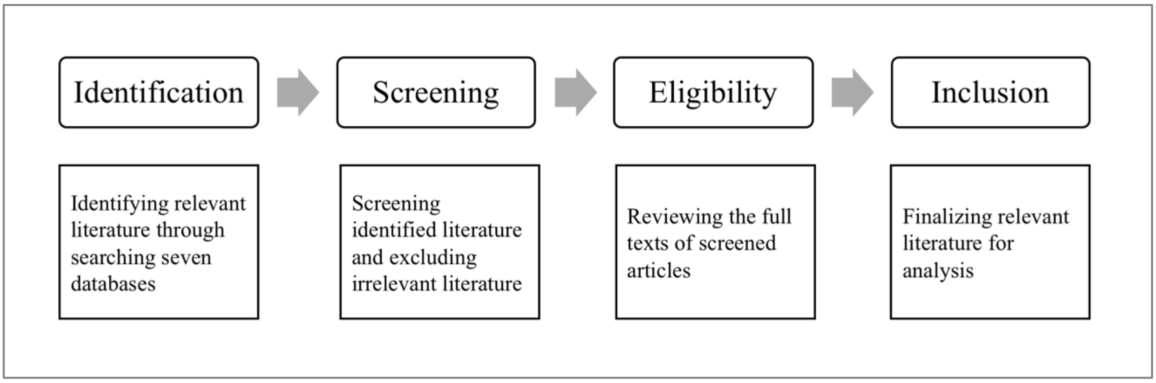


Figure 1. Article Selection Process Adopted and Adapted.

Considering the purposes and questions of this study, we used the following keywords to search and identify relevant literature: (Robot OR Robots OR Robotics OR Robotic) AND (Learning OR Education OR Educational OR Teaching OR Teaching OR STEM). In the process of identification and screening, we set up and used the keywords to identify and include articles that were appropriate for and relevant to this study. First, we searched for and selected studies published between 2004 and 2015. Given that this study aimed to investigate changes in research trends in r-Learning over time, we wanted to consider at least a decade of publication years for our review. The most recent studies on r-Learning, published from 2016 to the present, are still under review by us with different research questions. Second, we included studies targeting a wide range of students' ages, from preschool and kindergarten children (age 3 – 5 years old) to university-level undergraduate students. Third, we searched for empirical studies that implemented r-Learning for students. We included empirical studies that provided r-Learning in both formal educational settings (e.g., regular classrooms in schools) and informal educational settings (e.g., summer camps and afterschool programs). Last, we searched for empirical studies that employed physical forms of educational robots rather than digital and software programs.

Although we used the above keywords and criteria, the initial search returned some non-relevant or overlapping articles. For this reason, we excluded studies that were duplicated in other databases. We also excluded articles which did not employ educational robots or did not provide students with opportunities to interact directly with the educational robots. Through this process, we finalized a list of 843 studies about r-Learning for review in this study.

2.2 Data Analysis

The four research questions guided our data analysis. We purposefully read the selected 843 studies and analyzed each article based on the publication year, students 'age and characteristics, educational activities of r-Learning, and trend in educational robots. While summarizing the findings, we analyzed and systemically categorized patterns that emerged from the findings. At the same time, we attempted to quantify the findings by analyzing them in percentage terms.

3. Results

3.1 Trend of Research on R-Learning

We analyzed how research on r-Learning changed over the decade by tracking the numbers of published articles relating to r-Learning. To be specific, 128 papers were published from 2004 to 2007 (15.2%), 306 were published from 2008 to 2011 (36.3%), and 402 were published from 2012 to 2015 (48.5%). As Figure 2 presents, research in the area of r-Learning steadily and dramatically increased from 2004 to 2015. Given that 25 papers were published in 2004 and 117 papers were published in 2014, there was a 4.8-fold increase within ten years.

The explosive growth in the amount of studies about r-Learning implies not only growing popular interest in but also sustained focus on r-Learning. Thus, it is expected that the current academic interest in r-Learning will be sustainable in future years. Looking ahead, we need to focus on increasing the quality of research on r-Learning as well as the quantity.

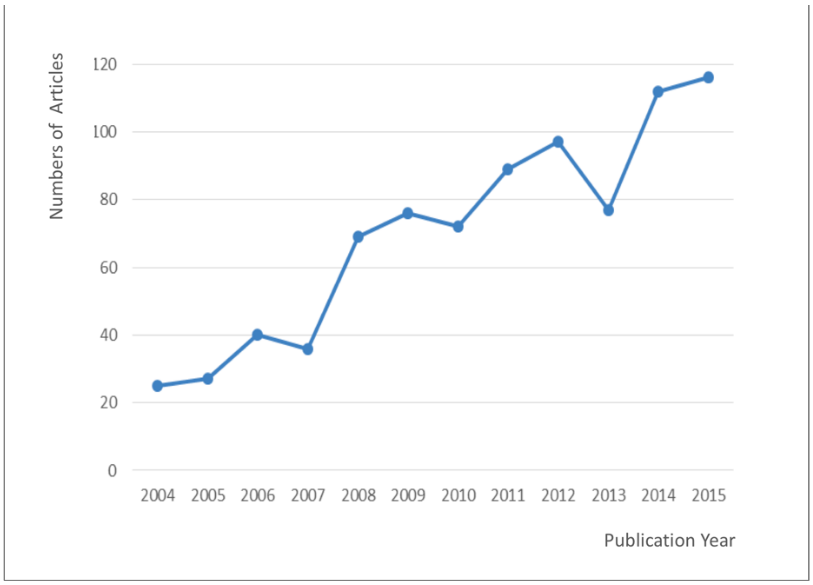


Figure 2. The Change in the Number of Articles on R-Learning

3.2 The Characteristics of Targeted Student Populations

Our analysis indicates that 9% of reviewed studies implemented r-Learning for preschool and kindergarten students (3-to 5-year-old children) and 13% of studies provided r-Learning to elementary school students. Also, 6% of reviewed studies on r-Learning targeted middle school students, and 10% of studies were about r-Learning for high school students. Another 24% of the studies targeted undergraduate students in universities. Lastly, 38% of reviewed articles targeted mixed groups of students (see Figure 3).

As the percentage ratios in Figure 3 show, the studies targeting mixed groups of students comprised the largest proportion of the reviewed literature. We considered mixed groups of students to be mixed-age groups that mostly consisted of elementary, middle, and high school students. This result is related to the educational settings and contexts of r-Learning. Many educational programs for r-Learning were provided by summer camps, afterschool programs, robotics competitions, and museums. For this reason, the informal educational programs targeted and recruited a broad range of students, regardless of their ages.

The highest percentage of articles in our review involved undergraduate students. This result indicates that universities have attempted to invest in r-Learning by purchasing expensive educational robots and improving courses. It can be understood that universities are making an effort to provide high quality teaching with innovative educational technologies. Also, this result mirrors the fact that universities adopt r-Learning in order to prepare their students for STEM careers and meet the demands of the Fourth Industrial Revolution.

It is worth pointing out that preschool and kindergarten students also engaged in r-Learning. Although they were the youngest group of students, the results show that they were able to learn robotics concepts and skills (e.g., computational thinking, coding, and the engineering design process) with developmentally appropriate educational robots. The most recent research in our study examined preschool and kindergarten children's r-Learning, and further research is needed on adoption of r-Learning for this age group.

Among the 836 articles, we found that only one paper targeted in-service teachers. The number of papers targeting teachers was very low; however, pre-service and in-service teachers play an important role in r-Learning. While the value of r-Learning for all age groups is increasingly acknowledged, there is a lack of teachers who are trained in r-Learning and who have the skills to implement it in regular school settings. In fact, the majority of r-Learning has been developed in extra-curricular settings and provided by robotics experts and STEAM mentors (e.g., engineering undergraduate students), not school teachers. Thus, more research targeting both preservice and in-service teachers is needed so that r-Learning can be integrated with the regular school curricula, the contents of diverse subjects, and the pedagogical knowledge which teachers are already familiar with.

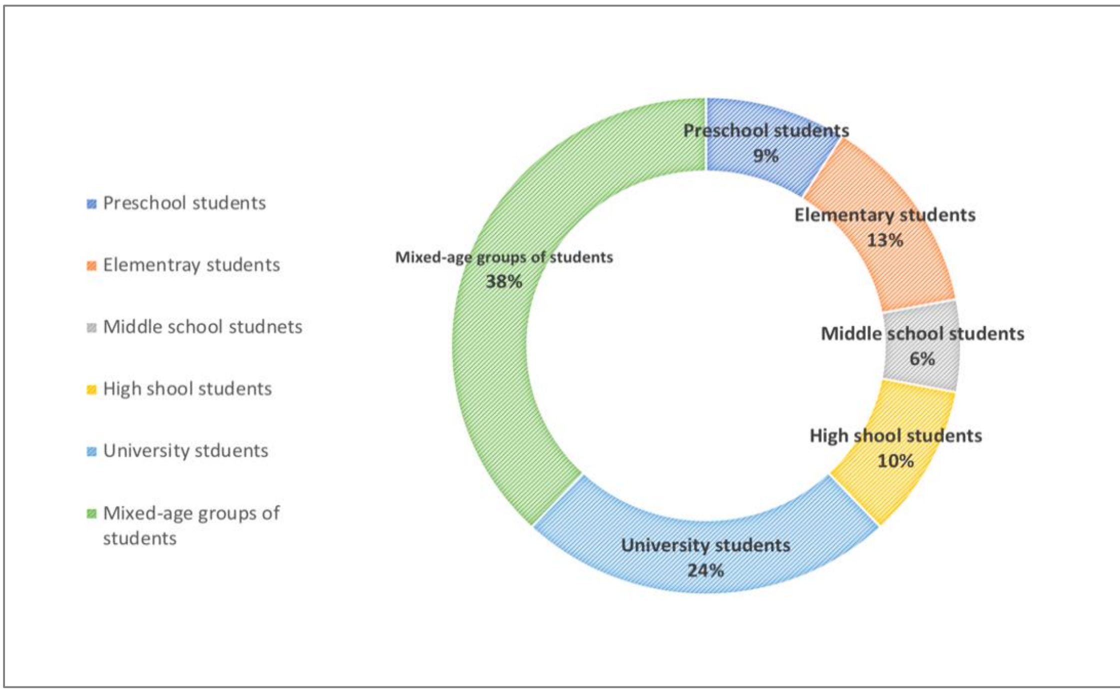


Figure 3. Ages of Targeted Students

3.3 Educational Activities Using r-Learning

We analyzed the selected articles by examining types of educational activities that involved r-Learning. As Figure 4 presents, 26% of studies engaged the targeted students in activities for programming robots, and 38% of studies provided students with activities for building and programming robots. The former studies employed commercial robots (e.g., BeeBots and Ozobots) which were produced by companies and labs. Students learned to program and manipulate the commercial robots by using different types of programming languages such as a block-based visual programming language (e.g., Scratch). In the latter case, the studies engaged students in activities for both building and programming robots. The learning objectives of the activities were to facilitate students' learning of not only how to program robots but also how to design and build the robots. LEGO Education WeDo and LEGO Mindstorms are popular robots for these types of activities, and they allowed students to have the autonomy to design and construct robots as they wanted. The remaining 38% of studies engaged students in activities which used autonomous types of educational service robots such as IrobiQ, KindSAR, and NAO. Students did not program or build robots but employed the robots for their learning in different subject areas (e.g., reading books, singing songs, or playing math games). These can be understood as robot-assisted learning activities.

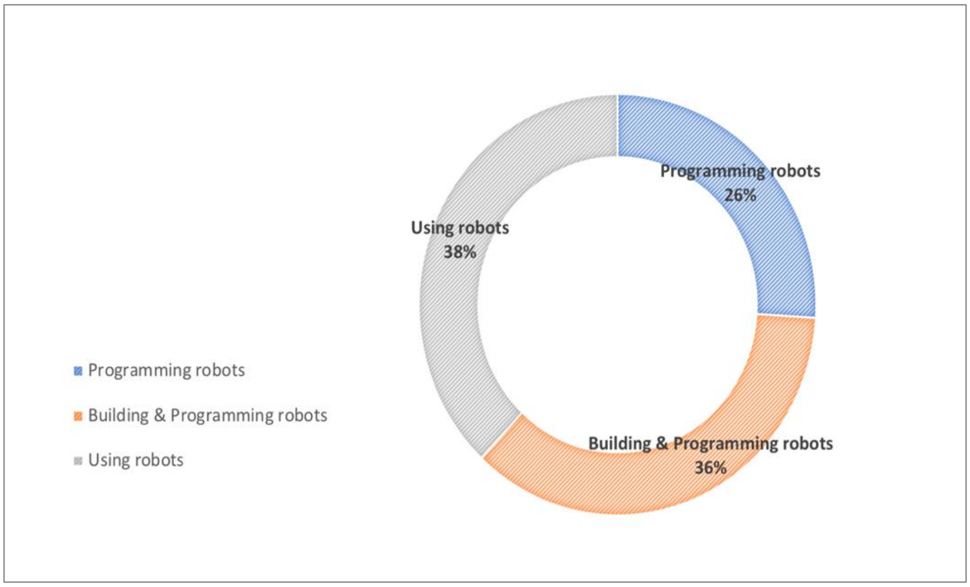
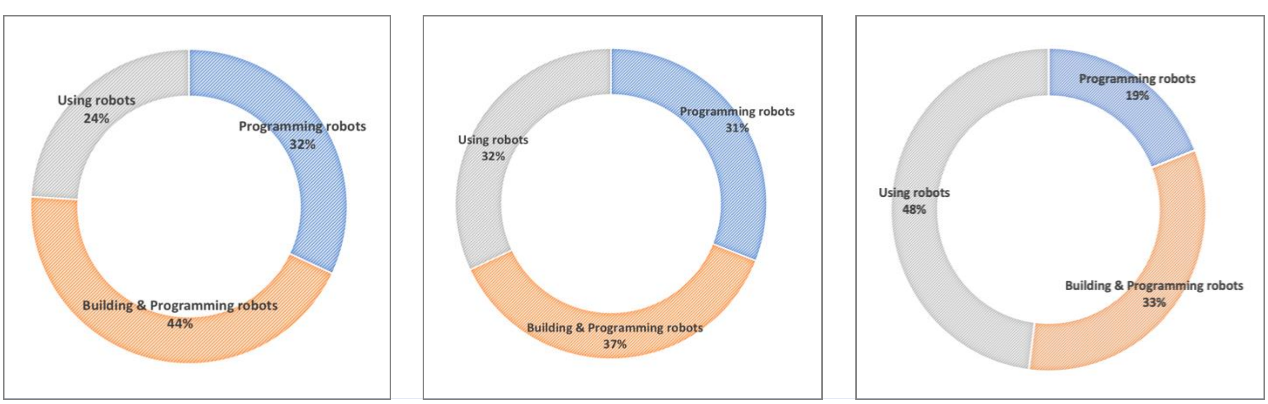


Figure 4. Types of Educational Activities Using r-Learning

Next, we analyzed how the types of educational activities using robots changed over time. We separated the publication years into the following three periods to ensure clear comparisons: (a) Period I, (b) Period II, and (c) Period III. As Figure 5 shows, the percentage of r-Learning activities that only involve programming robots has steadily fallen. The percentage of activities that include both building and programming has declined slightly, from 44 % to 33%; however, the activities has constantly implemented for r-Learning. In particular, the change in the percentage of activities with autonomous types of educational service robots merits attention. The percentage of studies that implemented learning activities with service robots increased greatly, from 24% to 48%.



(a) Period I (2004-2007) (b) Period II (2008-2011) (c) Period III (2012-2014)

Figure 5. The Percentage Changes of Educational Activities at Different Time Periods.

So, what do these changes in the types of activities for r-Learning mean? First, programming continued to be emphasized. Students were exposed to programming robots for learning algorithmic thinking as computational thinking, coding vocabulary (e.g., debugging, command, loop, and parameter), and problem-solving. Coding was continuously stressed as a 21st-century skill. In particular, the physical presence of educational robots in r-Learning played a critical role in providing tangible and interactive experiences for learning programming. Second, the content of r-Learning was expanded by including activities for designing and building robots. It can be understood that the designing and engineering aspects have been gaining attention as essential skills that students should learn through r-Learning. The designing and engineering aspects of r-Learning are aligned with the interdisciplinary nature of STEM. Last, activities using autonomous types of educational service robots became common in r-Learning. As a kind of educational technology, educational robots are considered to be teaching and learning assistants for learning other subjects, not for learning robotics itself. In this case, students acquired technological knowledge by understanding how they can adopt the educational service robots for their own purposes and by becoming familiar with innovative new technology such Artificial Intelligence.

3.4 The Types of Educational Robots Used for R-Learning

In our analysis, we again divided the publication years into the following three periods to analyze what types of educational robots were used during each period: Period I, Period II, and Period III. Also, we identified the following three types of educational robots: 1) user-buildable robots, 2) educational service robots, and 3) convertible robots.

128 studies of r-Learning were conducted during from 2004 to 2007 (period I). Our analysis demonstrated that 76.6% of those studies employed user-buildable robots and 23.4% used educational service robots. We could not find any articles which adopted convertible robots during this period. However, one study in this period used a robot placed at the intersection between the educational service robots and user-buildable robots.

During the second period (from 2008 to 2011), the user-buildable robots were the most frequently used (62.7% of the studies). In addition, 36.6% of studies employed educational service robots and 0.7% used convertible robots. As the numbers of papers indicate, the percentage of studies involving user-buildable robots increased significantly – compared to the percentage of the studies in the first period. This result is aligned with the changes in types of educational activities used in r-Learning. As both programming and building robots were emphasized in r-Learning, the user-buildable robots were adopted as an appropriate educational means for programming and building. However, the convertible robots were rarely used during the second period.

In our analysis of the third period (from 2012 to 2015), we found that 57% of the studies used user-buildable robots, 38.3% employed educational service robots, and 4.2% utilized convertible robots. Just 0.5 % of the studies used educational robots placed at the interaction between user-buildable robots and educational service robots. The percentage of the studies using convertible robots slightly increased.

Considering the patterns of types of educational robots during the three periods, it is noticeable that the types of educational robots used in r-Learning became gradually more diversified. As Table 1 below presents, many studies employed mostly user-buildable robots during the early period. While the proportion of studies using user-buildable robots decreased as the years went by, the percentage of studies involving educational service robots and convertible robots increased. This reflects the influence of the active development of new robotic technology in the robotics industry and the rapidly growing societal interest in AI technology. For example, the convertible robots were more accessible to students for their r-Learning via community-based or international events such as Maker Fairs – events that introduce and celebrate innovative projects and creative minds. Also, as we discussed in the above section, the diversity of the types of educational robots contributed to expanding the content of r-Learning.

Table 1. The Percentage Changes of Types of Educational Robots

Types of Educational Robots	*Period I (2004 - 2007)*	*Period II (2008 – 2011)*	*Period III (2012 - 2015)*
User-buildable robots	76.6%	62.2%	57.0%
Educational service robots	23.4%	36.6%	38.3%
Convertible robots	0	0.7%	4.2%

4. DISCUSSIONS

Based on the findings of this study, we present our conclusions, suggestions for further research, and implications for practice below.

First, it is evident that the research on r-Learning has rapidly and steadily increased. Also, it is expected that further research on r-Learning and educational programs for r-Learning will continue to grow in volume. Johnson also agreed that the popularity of r-Learning is more than a fashion and it will last [14]. However, r-Learning is not a new field any more. We suggest shifting our attention from quantitative growth to growth in quality. Rather than superficially reporting what kinds of r-Learning experiences were given to students, future research needs to validate the effectiveness of r-Learning in a systemic way and enhance the research methodology and methods. In particular, Alimisis argued that quantitative evaluation and reliable research design are needed to measure the impact of r-Learning with evidence [15].

Second, it was found that the previous studies focused on students of all ages. It is meaningful that some studies targeted preschool and kindergarten children. Those studies contributed to showing the potential of r-Learning for young children by ensuring early access to STEM and lowering the entry point into robotics. However, regarding the characteristics of the targeted populations for r-Learning, we think that the previous studies were limited to the age-boundaries. For the future research, we suggest to broaden its perspective on the target population of r-Learning.

Again, as we mentioned in the results section, there were very few studies that provided r-Learning to teachers. While the benefits of r-Learning have been recognized by researchers, teachers tend to consider r-Learning an extra-curricular activity provided by robotics experts outside of school settings [16]. Teachers already have rich experiences in pedagogy, expertise in different teaching methods, and content knowledge of different subjects; however, the majority of teachers do not have enough opportunities to learn how to implement r-Learning effectively in their classrooms [17]. Thus, we suggest that future research should focus on the teacher population in order to ensure the long-term impact of r-Learning. Also, we call attention to underrepresented groups of students in r-Learning. For example, it is reported that female and cultural/linguistic minority groups of students have participated less in STEM-relating careers [18]. We believe that research on and practice in r-Learning can be a means of boosting non-mainstream students' participation in STEM.

Third, it was revealed that both programming and building robots were emphasized as educational activities for r-Learning and that robot-assisted activities for different subjects increased over the period we investigated. The stress on activities for programming and building robots is parallel to the current emphasis of Next Generation Science Standards (NGSS) [19]. R-Learning can provide students with tangible opportunities to directly engage in engineering practices such as defining problems; developing and using models; planning and carrying out investigation; analyzing and interpreting data; using mathematical and computational thinking; designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information. We suggest improving the educational activities for programming and building robots by making clear connections to engineering practices and the engineering design process [20]. Also, we think the design aspect of robotics was missing in the previous studies. Therefore, the artist and maker's mindset should be considered and included in educational activities for r-Learning from the stance of STEAM education (beyond STEM).

Lastly, it was shown that the types of educational robots used in r-Learning diversified and the employment of educational service robots and convertible robots has increased. In analyzing the trend of educational robots, we identified three different types of educational robots (user-buildable robots, educational service robots, and convertible robots). It is significant that this study used the conceptual framework of types of educational robots to review the literature of R-learning. as there is lack of a consistent and universal conceptual framework to define educational robots. The previous studies did not clearly define or name what types of educational robots they used – instead, the studies tended merely to describe the technological traits of the educational robots. Furthermore, the studies used their own terms for the educational robots. Thus, we argue that there is an urgent need for conceptual studies that can develop and propose systematic definitions of types of educational robots based on theories and rigorous research on robotics and educational technology.

5. CONCLUSION

As a comprehensive literature review study, we investigated 1) the trend of research on r-Learning over time, 2) the characteristics of targeted students in r-Learning, 3) the educational activities implemented for r-Learning, and 4) the types of educational robots used for r-Learning. This study is meaningful in that a vast volume of research data on r-Learning – 843 previous studies published during a recent ten-year period (from 2004 to 2015) – was examined. This study contributes to expanding knowledge on r-Learning by identifying strengths of and gaps in the previous literature. Again, the most recent studies on r-Learning published from 2016 to the present are still under review with different research questions. It is suggested that the findings and implications of this study should be taken into account for designing and conducting literature review research on studies of r-Learning published after 2016.

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