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Systematic Literature Review (SLR): An In-Depth Review of Robotic Learning with Quasi-Experimental Methods from Pre-School to High School

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Abstract

The increasing presence of robotics in education raises the need for a deeper understanding of the effectiveness of robotic learning. This study focuses on a systematic literature review (SLR) of quasi-experimental robotics learning, ranging from preschool to high school. This research aims to detail and investigate various quasi-experimental approaches in robotics learning, focusing on the age range from preschool to high school and to understand the impact on learners after the robotics learning process. This research uses the SLR approach to collect, evaluate, and synthesize current findings in the literature in the form of articles in reputable international journals spanning the years 2018-2023 regarding quasi-experimental robotics learning. The analysis was conducted to identify common trends, weaknesses, and strengths of the methods applied. The results highlighted the variety of quasi-experimental designs used in robotic learning. Based on 15 articles, 10 used pure Quasi-experimental design, and 5 used Mixed Method. The findings provide an in-depth understanding of the effectiveness of the various approaches, enabling robust conclusions to be drawn to improve robotics learning at different levels of education. This review contributes to the literature by identifying new findings using quasi-experimental methods in robotics learning and under-researched research variables. Its significance lies in furthering the understanding of the variables studied and the effectiveness of robotics learning at different stages of education. This research provides a solid knowledge base for developing more effective robotics learning strategies, positively contributing to the advancement of educational science and providing long-term benefits to society by improving the quality of robotics education.

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INTRODUCTION

21st century education demands rapid adaptation to technological developments, focusing on integrating innovations in learning methods. One area that is gaining increasing attention is robotics learning at secondary, primary, and preschool levels. Robotics learning has the potential to enhance technology skills and problem-solving abilities, as well as assist students in developing a deeper understanding of concepts in science and technology.

It is anticipated that 65% of elementary school students will work in new, nonexistent jobs due to technological advancements (Çalişkan, 2020). Essential 21st-century abilities that the workforce has to develop to adapt to these changes include critical thinking, problem-solving, communication, teamwork, creativity, and invention. It is often known that teaching robotics stresses the development of computational thinking and problem-solving skills, making robotics education an effective and flexible teaching tool. Using robots to teach programming can increase student engagement and help them become better problem solvers.

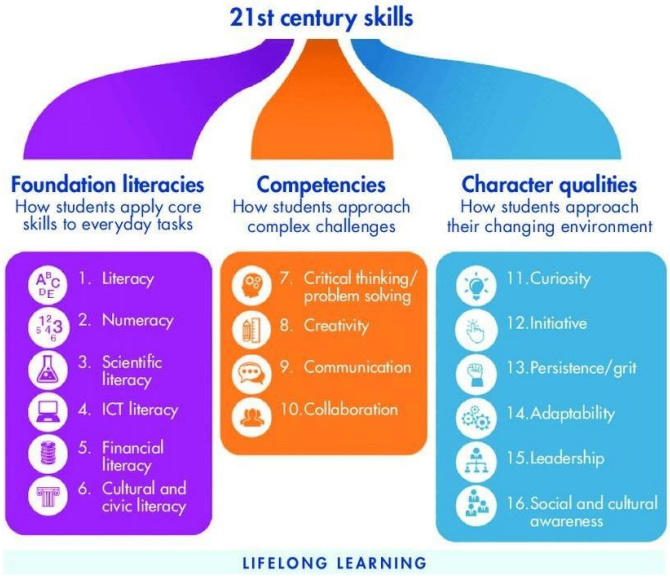

Figure 1. 21st Century Skills (World Economic Forum, 2015)

The World Economic Forum (2015) suggests that 21st-century skills that the younger generation must possess are divided into three parts: Foundation Literacy (Basic Literacy), Competencies, and Character qualities, where each part has its own aspects.

In STEM Education, one way to address this educational difficulty is via STEM-based learning (P4TK IPA West Java, 2019). Teachers can show students how concepts, theories, and techniques from several disciplines are combined to create products, services, and systems that they use daily through STEM education. Consequently, an interdisciplinary approach to learning is accepted as the definition of STEM education (Reeve, 2013). Students can develop STEM literacy by utilizing STEM subjects in real-world scenarios that connect the classroom, workplace, and international society, preparing them for success in the twenty-first century."

Activities involving robotics can provide relevant settings for integrated STEM education experiences that help students apply their knowledge and abilities and better grasp the links among various STEM fields (Ching et al., 2019). So, we can see that Robotics and STEM can improve the 21st-century skills that today's young generation must possess. Various studies havebeen conducted, including 15 articles from international journals that are the main focus of this systematic literature review (SLR). Concentrating on quasi-experimental methods, this research intends to provide a critical review of the approaches applied in the context of robotics learning. Therefore, an in-depth understanding of

the contribution of quasi-experimental methods to robotics learning can be an important foundation for developing effective and responsive educational strategies. As such, this study aims to provide critical and in-depth insights into the existing literature, promote a better understanding of the application of quasi-experimental methods in robotics learning at primary and secondary education levels, and provide direction for future research and practice.

METHODS

Research for Systematic Literature Reviews (SLR) is carried out for several reasons, such as finding, reviewing, assessing, and interpreting all existing studies on the phenomenon of interest and defining pertinent research questions (Triandini et al., 2019). The objectives of this research are the quasi-experimental method in the context of robotics learning in secondary, primary, and pre-school settings. This choice was made because the quasi-experimental method closely approaches the pure experimental research method and proves suitable for educational research. Robotic learning is a current learning that must be developed, and this robotic learning supports 21st-century skills. The development of robotic learning by supporting 21st-century skills uses the best research methods.

1. Research Question: The formulation of the research question is guided by the requirements of the chosen issue. The study's research questions are as follows:

   RQ1. What *tools* in robotics learning are frequently used from 2018-2023?

   RQ2. Which research techniques are frequently applied in robotics education?

   RQ3. What are the 21st-century skills that are often examined in such robotics learning research?
2. The Search Process is employed to find pertinent sources and additional related references in order to respond to the Research Question (RQ). Eric.gov was used for primary data, *Publish or Perish* was used for secondary data, and https://www.google.com was used for primary data.
3. Inclusion and Exclusion Criteria. This step determines whether the discovered data can be used for SLR research. Studies ought to be chosen if the following conditions hold:
   a) The data used spans 2018-2023.
   b) Data obtained from *Publish or Perish, Google Scholar, and eric.gov* forprimary data.
   c) The data used is only related to robotics learning.
4. Quality Assessment. The data discovered in the SLR study will be assessed using the following questions from the quality assessment criteria:

   QA1. Will journal papers be published in 2018-2023?

   QA2. Does the journal paper list the research methods often used in learningrobotics?

   QA3. Does the journal paper list the 21st-century skills often examined in robotics learning research?
5. Data Collection. the phase in which research data is gathered. This study's data collection comprises both primary and secondary sources.
   1) Primary Data. Data was gathered and customized based on observations, interviews, surveys, and other methods. For the following reasons, articles from *Publish or Perish* and eric.gov were used as the primary sources of data for this study:
      a) Publish or Perish, and eric.gov provide complete facilities.
      b) The data can be readily searched because it contains a range of years that the researcher can modify to suit their needs.
      c) You can alter the data that is shown as needed.
   2) Secondary Data. Secondary data complements source data; if the source data consists of abstracts, then supplementary data is required. We get secondary data with Google's assistance. The study's data was gathered in several steps, including:
      a) Observation
         This phase involves gathering data using direct observation at the source, which in this case is eric.gov, and publish or perish.
      b) Literature Study
         This step involves conducting data review research on articles from eric.gov, *Publish or Pherish* connected to the SLR Method.
      c) Documentation

At this point, the gathered data is saved to the laptop's hard drive.

The procedures for gathering data are as follows: observation, followed by documentation from sources like *Publish or Perish*, and eric.gov

- To *Publish or Pherish,* download the application first on the site *Publish or Pherish*, then install, and open the app.
- Select or check the source that we will search for example check *Google Scholar*
- Enter the keywords "robotic, learning" in the search *keywords*.
- select the year range we want to select
- then click *search.*

for sources from *eric.gov*

- Visit *eric.gov* sites
- Enter the keywords "*robotic, learning*" in the search *form*.

6. *Data Analysis.* At this point, the gathered data will be examined to demonstrate:
   a) *Tools* in robotics learning that are often used from 2013-2018 (referring toRQ1).
   b) Methods/approaches often used in robotics learning (refer to RQ2).
   c) 21st century skills that are often investigated in robotics learning research (referring to RQ3).
7. *Deviation from Protocol.* Following the review, the author made minor adjustments to the procedure variation.:
   a) This research identifies the research methods, tools used, and skills studied in robotic learning, and answers the *research question*.
   b) Gather journals in order to respond, guarantee quality, and supply the necessary data.
   c) Extend this study's explanation of SLR.

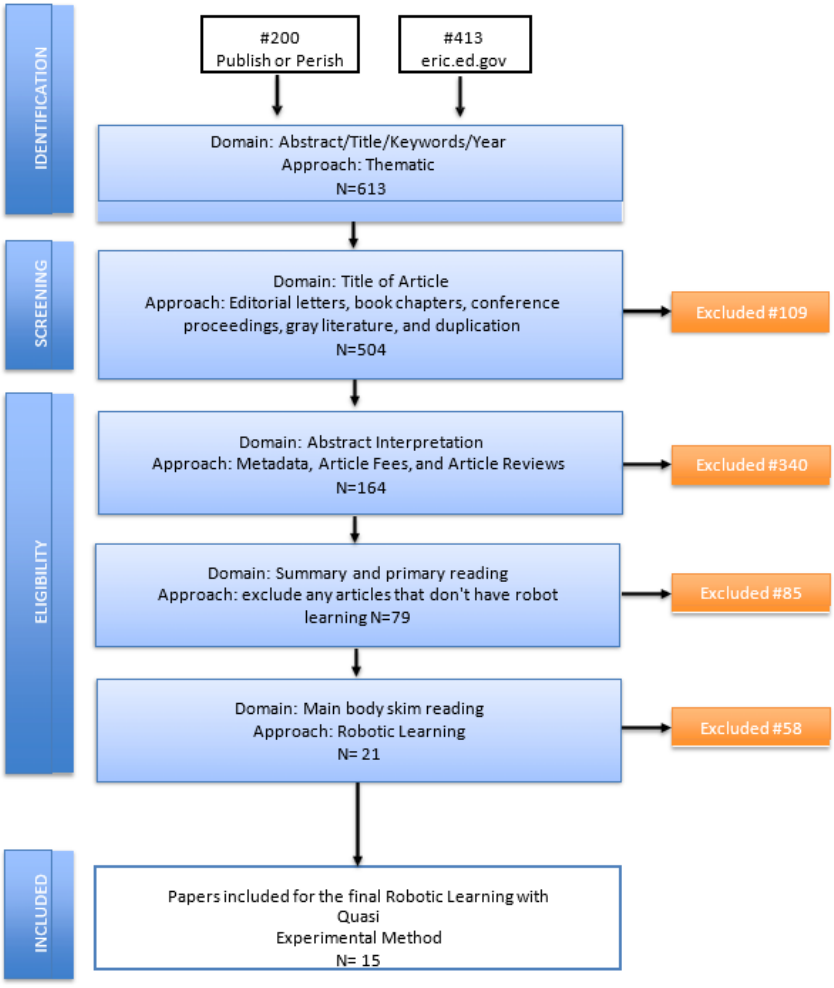

Figure 2. The flow diagram for the database search of publications for systematic reviews. Source: Modified from (Moher et al, 2010)

RESULTS AND DISCUSSION

Based on the search results using the SLR method, 15 articles from reputable international journals were obtained. These 15 articles were then analyzed, and the data analysis table for these 15 articles is presented below:

Table 1. Article in International Journal on Robotics in Learning

No	Article Identity	Novelty	Conclusions	Recommendations
1	Title: The effects of robotics programming on secondary school students' problem-solving skills Author: Erkan Çalişkan	the effect of Robotics Programming on problem-solving skills in secondary school pupils	that teaching high school pupils to program robots aids in their problem-solving abilities. Furthermore, there is an increase in students' perceptions of their ability to solve problems.	more valid experimental study designs
2	Title: Elementary School Student Development of STEM Attitudes and Perceived Learning in a STEM Integrated Robotics Curriculum Authors: Yu-Hui Ching et al.,	the use of robotics-integrated STEM learning approach in an informal learning context	Students' views of STEM learning and their attitudes toward math can both be improved by robotics curricula that include STEM. Pupils ' perspectives remained mostly unchanged regarding science, engineering, and technology. Students also showed an interest in science education, particularly regarding the subject of life on Mars.	expand the scope of this research by involving more students and teachers from various backgrounds. In addition, the use of more complete instruments to measure students' attitudes towards STEM and expand the focus of the study to look at the impact of the program on students' technical skills. the use of more advanced technology in STEM integrated robotics learning to increase students' interest and skills in STEM.
3	Title: Effects of Robotics Education on Young Children's Cognitive Development: a Pilot Study with Eye-Tracking Authors: Yan Liu, et al	Further insights into how robotics education influences young children's cognitive processes can be gained by measuring the effects of robotics education on their cognitive processes using eye-tracking technology. Early children's cognitive development may be impacted by robotics learning.	Early childhood robotics education can benefit young children's cognitive development.	Future research should use more controlled experimental designs and more rigorous measurement tools to obtain more rigorous empirical evidence, considering contextual factors that may affect the effectiveness of robotics education, such as learning environment and student characteristics

4	Title: The Impact of an Integrated Robotics STEM Course with a Sailboat Topicon High School Students' Perceptions of Integrative STEM, Interest, and Career Orientation Authors: Chen, Y. H., & Chang, C. Y.	The novelty lies in the integrative approach used in the robotics curriculum and the focus on using opensoftware and hardware.	1. A STEM robotics curriculum integrated with sailboat topics can improve students' perception, interest,career orientation, and satisfaction with STEM learning. 2. Following the program increased the students' comprehension of physics, arithmetic, mechanics, electronics, robotics, and sailboat design ideas.	Expanding the scope of research subjects, increasing the number of STEM topics, longer duration,anduse of robotics technology.
5	Title: Cognition, Attitude, and Interest in Cross-Disciplinary i-STEM Robotics Curriculum Developed by Thematic Integration Approaches of Webbed and Threaded Models:a Concurrent Embedded Mixed Methods Study Authors: Chi-Cheng Chang andYiching Chen	the cross-disciplinary integrative approach used in the development of the i-STEM curriculum, as well as the use of a mixed research design that included embedded qualitative methods to understand more deeply students' cognitions and attitudes towards STEM robotics after learning	The cross-disciplinary integrative robotics i-STEM curriculum can enhance students' understanding, motivation, and enthusiasm for STEM robotics. In addition, this study also shows that an embedded mixed research design can provide a deeper understanding of the effects of STEM robotics learning on students.	Number of research subjects, comparing STEM robotics and general robotics, valid instruments
6	Title: Educational Robotics in Primary School: Measuring the Development of Computational Thinking Skills with the Bebras Tasks Authors: Giuseppe Chiazzese,et al.	Measuring the impact of robotics laboratorieson the development of computational thinking skills using Bebras Tasks as a measurement tool	participation in robotics laboratory activities can contribute to the improvement of computational thinking skills in elementary school students	Larger research subjects, other measurement tools, design of educational activities accordingto the level of child development
7	Title: Investigating the use ofrobotics to increase girls' interest in engineering during early elementary school Authors: Amanda Sullivan, Marina Umaschi Bers	a focus on using robots (KIBO) to modify children's perceptions of STEM areas in early childhood education (ages 5-7). Additionally, instructors' roles in influencing girls' performance and enthusiasm in programming activities are highlighted.	Early exposure to KIBO's 7-week robotics curriculum may encourage girls to pursue careers in engineering.	Examine how youngsters respond to and handle technical setbacks and challenges differently depending on their gender. broaden and diversify the scope of this study by examining how teachers affect females' interest in and performance on programming challenges.
8	Title: The effect of programming on primary school students' mathematicaland scientific understanding Author: Sáez-López, et al	the relatively recent adoption of programming and robotics as instructional methods in elementary schools	Incorporating robots and programming into elementary school curriculum helps enhance pupils' comprehension of science and math concepts.	Larger research subjects, considering the use of roboticsand programming in other learning contexts, the use of other advanced technologies
9	Title: Exploring the Effects ofNear-Peer Teaching in Robotics Education The Role of STEM Attitudes (Quasi single group pre pos) Authors: I.C. de Vink, et al	The significance of STEM attitudes in the educational process and the use of peer teaching in robotics education	Students' attitudes toward engineering and technology can be positively impacted by peer teaching in the context of robotics instruction.	the impact of peer teaching in the context of robotics education and students' STEM attitudes in greater depth, and to identify peer teaching strategiesthat are more effective in influencing students' STEM attitudes.

10	Title: Effect of coding and robotic education on pre-schoolchildren's skills of scientific process Authors: Turan, S., Aydoğdu, F	how STEM education can be applied to early childhood and how it can influence the development of their scientific skills	Early instruction in robotics and coding has a beneficial effect on young children's development of scientific process abilities.	Larger sample subjects, research on early childhood inother skill aspects, research onother age groups
11	Title: The Effect of Robotics- Based Storytelling Activities on Primary School Students' Computational Thinking Authors: Tengler, K, et al	a method known as Tell, Draw, and Code that uses instructional robotics and storytelling to encourage computational thinking.	Using robotics to tell stories, particularly the Tell, Draw, and Code approach, can help primary school kids become more proficient in computational thinking.	The existence of a control group,validation of different design principles, involving teachers as research subjects
12	Title: Effects of robotics programming on the computational thinking and creativity of elementary school students Authors: Jiyae Noh, JeongminLee	This study offers fresh empirical data on how teaching programming with robots affects elementary school pupils' computational thinking and creativity.	Elementary school pupils' computational thinking and creativity can be enhanced by teaching programming with robots. Teaching and learning strategies that incorporate the four-component learning design model (4C/ID) and consider computational thinking's constituent parts can help foster computational thinking and creativity. learning goals for students pursuing robotics education	Broader subjects, using other variables, interest, motivation, using control groups, research on gender differences in student learning outcomes.
13	Title: Innovation of TeachingTools during Robot Programming Learning to Promote Middle School Students' Critical Thinking Authors: H. Liu, J. Sheng, L.Zhao	on innovative learning tools used during robot programming lessons, by comparing two different instructional design approaches to see their effect on thinking skills. student critical thinking	Students' critical thinking abilities are greatly enhanced when they study robot programming using the CCM (Construction, Criticism, Migration) approach.	Subject to a wider research sample, consider the factor of and the influence of scientificliteracy and cognitive load onthe effectiveness of robot programming education.
14	Title: Arduino-assisted robotics coding applications integrated into the 5E learning model in science teaching Author: Gokhan Guven, et al	Study synthesis on the impact of the 5E learning strategy (Engage, Explore, Explain, Elaborate, Evaluate) and the Arduino-assisted robotics coding curriculum on students' scientific and robotics-related attitudes.	Shows how incorporating an Arduino-assisted robotics coding application into the 5E learning model can enhance students' willingness to learn science, scientific inventiveness, and attitude toward robotics.	Greater sample size, a control group, additional impact on academic performance, and comparison with alternative learning models
15	Title: Augmented Reality and Competition in Robotics Education: Impact on Students' Motivation, Collaboration, and21st Century Competencies Author: Ching-Huei Chen, Chih-Hsiung Tu, and Chia- Hua Chuang	Using Augmented Reality (AR) technology and organizing a tournament for robotics instruction	The integration of Augmented reality (AR) and robotics contests into educational activities can greatly enhance students' enthusiasm to learn, their ability to collaborate in a team, and their 21st-century competencies.	Duration of research, impact onlearning outcomes

Based on this table, the author sees that there are several designs of quasi-experimental methods in the research used

Table 2. Quasi-Experimental Design of 15 Articles

No.	Quasi-Experiment Design	Number ofArticles
1	Pre-Post with Control Group	4
2	Pre-Post Single Group	5
3	Post Only with Control Group	1
4	Mixed Method with Control Group	2
5	Mixed Method Single Group	3

Based on Tables 1 and 2 above, we can see that most journals have advantages regarding research methods. However, in the single-group design, both mixed and quasi-experiments point out that the analysis technique is flawed because there is no control group to compare the research. Despite this, single-group designs are the most popular among journal researchers.

Quasi Experiment post only with the Control Group is the least chosen by researchers, although it is said that the research method is the strength of the journal. with this research, we do not know the initial condition of the research subjects because the analysis technique is incomplete. Therefore, using this method may bring limitations in thoroughly describing the experimental group's initial picture, reducing the research findings' validity and reliability.

Then, in the research method using Mixed Method with Control Group in Table 1, it is evident that the researcher did not point out any shortcomings in the analysis technique. This indicates that the analysis technique was deemed adequate or good enough in articles that conducted research using this design method. Therefore, it is reasonable to believe that the study's Mixed Method with Control Group approach was applied meticulously and carefully, providing confidence in the validity and dependability of the research findings.

The mixed method is explained as a research approach that combines quantitative and qualitative approaches in one research study; in this mixed method allows researchers to collect and analyze data from various sources, thus providing more comprehensive and in-depth insight into the phenomenon under study (McCrudden et al., 2020). Mixed methods also allow researchers to combine the strengths of quantitative and qualitative approaches, thereby increasing the validity and reliability of research findings by using data triangulation from multiple sources".

So overall, based on the research design of the 15 articles found there were five that used mixed methods, two studies that used mixed methods with a Control Group, and ten articles used Quasi Experiments; therefore, there is a significant variation in the selection of research design, which reflects the diversity of approaches taken by researchers in dealing with their research questions. By knowing this distribution, readers can understand more clearly the methodological trends emerging in the reviewed literature.

Table 3. Analysis of 15 Articles on the Integration of Robotics in Learning

No	Author	Year	Level	Robotic Tools	Research Methods	Research approach	Research Variables
1	Erkan Çalişkan	2020	School Medium	Modkit Vex Robtok	Quasi-experimental pretest-posttest without control group	Robotics programming	Problem solving skills
2	Yu-Hui Ching, et al	2019	Elementary School	Lego Mindstorms Education E V3robotics kit	Quasi-experiment pretest and posttest Nocontrol group, interviews	Robotics-integrated STEM learningin an informal learning context	Increasing students' interest and skills inSTEM

3	Yan Liu, et al	2023	Elementary School	Scratch program, robotics	Quasi-experimental pre-post test without control class, interview	Robotics Learning	Visual-space working memory ability and problem-solving ability, and social and emotional skills
4	Chen, Y. H., & Chang, C. Y	2018	School Medium	Arduino Uno	Quasi Experiment pre-post test class experiment and control class	STEM robotics learning	Perceptions, interests, career orientation, satisfaction and Student concept understanding
5	Chi-Cheng Chang andYiching Chen	2020	School Upper-Intermediate	Arduino Uno	Quasi Experiment pre-post without classcontrol	STEM robotics learning	Concept understanding, attitude, and studentinterest, as well as students' problem solving process
6	Giuseppeet al Chiazzese,	2019	Elementary School	Robotics Program, LegoRobotics	Quasi Experiment post-test only experimental class and control class	Robotics Learning	Computational thinking skills
7	Amanda Sullivan,Marina Umaschi Bers	2019	Pre-Primary School	Robotic KIBOsKIT	Quasi Experiment pre-post test class Experiment and control classes, questionnaires and observations	KIBO Robotic Learning	Girls' interest in engineering
8	J.-M. Sáez-López, et al.	2019	Elementary School	Mbot Robotics andScratch	Quasi Experiment pre post-test, class experimental and control classes, observation	Programming and robotics	Understanding of math and science concepts
9	I.C. de Vink, et al	2020	Elementary School	Arduino Uno, Scratch	Quasi experimental pre post withoutcontrol class	Robotics and STEM learning	Students' attitudes towards engineering and technology.
10	Aydin, B., & Tasci, D.	2019	Pre-primary school (kindergarten)	Coding program,O-Robotic bots	Quasi experimental pre post experimentaland control class	Coding and robotics program learning	Scientific process skills
11	Tengler, K	2022	Elementary School	Ozobot	Quasi Experiment pre post without classcontrol	Robotics-based learning	Computational thinking
12	Jiyae Noh, JeongminLee	2019	Elementary School	Robot Program, robotics	Quasi Experiment pre post without classcontrol	Robot programming learning	Computational thinking and student creativity
13	H. Liu, J. Sheng, L.Zhao	2022	School Me	Program Robotand	Quasi experimental pre post	Robot programming learning	Critical thinking skills

			diu m	Robotics	class experiment and control class			
14	Gokhan Guven, et al	2020	Elementary School	Arduino	Quasi experimental pre post without classcontrol, as well as quantiative (interviews)	Learning robotics coding	Scientif ic creativi ty, attitude towards robotic s, and motivation towards science learning	
15	Ching-Huei Chen, et al	2020	Sch ool Me diu m	AR, tools Robotic s	Quasi Experime nt Pre class post experime ntal and control	Learning robotics with AR	Learning motivation , collaborati on skills Team	

From Table 3 above, it can be seen that there are 2 research subjects at the pre- school level, 8 journals at the elementary school level, 4 journals at the middle school level and 1 journal at the high school level. This shows that the potential for robotic learning research is greater at the high school and pre-school levels.

Based on the approach and tools used in the research journals above, all levels userobotics-based learning and use robotic tools, meaning that this robotic learning uses robotic hardware in the process, although for pre-primary school levels the robotic tools used are easier to use than at other levels.

The following is an analysis table based on the research variables for each level:

Table 4. Analysis of Research Variables Based on 21st Century Skills

No.	Level	21st Century Skills									
		Basic Literacy				Competence			Character Qualities		
		Scientific	Computational Thinking	Concept Understanding	Critical Thinking	Problem Solving	Collaboration	Creativity	Attitude	Motivation	Interests
1	Pre School	√									√
2	Elementary School		√	√		√		√	√	√	√
3	Secondary School			√	√	√	√			√	√
4	Senior High School			√		√			√		√

According to Table 4 above, research variables at the pre-school level are still scarce, research has not been conducted in the Competency section of 21st century skills, nearly all aspects of 21st century skills have been researched at the elementary school level, and research has been conducted almost entirely at the secondary school level, with the exception of the Competency section, where the most research has been conducted. At the senior high school level, research has been conducted less frequently and there are still many aspects of 21st century skills that have not been researched; even at this level, Table 3 shows that there is only one study at this level.

We can also see that for the Pre-school and High School levels there are still many opportunities for research in the field of robotics with 21st century skills variables, although at the Primary and Secondary levels there are also aspects that have not been researched, such as at the Primary level in the Basic Literacy section aspects of the scientific process, in the Competency section aspects of critical

thinking, collaboration. For the Secondary School level in the Basic Literacy section there are aspects of the scientific process, and computational thinking, in the Competency section on aspects of creativity, and in the Character Quality section there are aspects of attitude, therefore, this insight provides direction for researchers to detail the potential research that can be done at each level of education with a focus on variables that have not been widely explored.

CONCLUSION

Based on the analysis of the quasi-experimental design table and the results of international journals on the integration of robotics in learning, it can be concluded that there are variations in the design of quasi-experimental methods used by researchers in robotics research at various levels of education. Pre-post single group and mixed method single group designs are the main choices, although there are shortcomings, especially in analysis techniques, due to the lack of a control group. In contrast, post-only quasi-experiments are a less popular choice. An analysis of international journals shows that robotics-based learning involves various levels of education, with a predominance at the primary school level. While most of the journals highlighted the strengths of their research methods, there were notable shortcomings, particularly in the single-group design, which lacked acontrol group.

Based on these findings, there are several suggestions for research and educational practitioners. First, there is a need for further research that explores the shortcomings of analytical techniques in single-group designs, especially in the context of pre-post quasi-experiments. Second, further research at the upper secondary and preschool education levels could be a promising area to gain further insights into integrating robotics into learning. Third, more in-depth research on 21st-century skills at specific levels (such as basic literacy, competencies, and character qualities) needs to be expanded to providea more complete picture of the impact of robotics learning. In addition, mixed methods research can provide a more comprehensive understanding of the phenomenon under study. Finally, researchers and educational practitioners should consider the diversity of quasi-experimental method designs and pay attention to potential shortcomings, especially related to data analysis. Thus, this study can contribute to developing more effective robotic learning strategies that are responsive to the needs of 21st-century education.

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