Cakrawala Pendidikan
Jurnal Ilmiah Pendidikan
Vol. 44 No. 3, October 2025, pp. 496-509
https://journal.uny.ac.id/index.php/cp/issue/view/2958
DOI: https://doi.org/10.21831/cp.v44i3.85086

Developing science inquiry skills in early childhood through coding games

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ABSTRACT

The 21st century requires education to equip students not only with academic knowledge but also with such as innovation, productivity, reasoning, programming, data literacy, problem-solving, and critical thinking, to face the rapid global changes. This study aims to develop science inquiry skills from early childhood to support children in mastering the competencies needed in the 21st century. The research employed a descriptive qualitative design. Data were collected from 16 preschools through observations, interviews, and documentation. NVivo was used for data management and analysis. NVivo is a software application that assist researchers in organizing, analyzing, and visualizing qualitative data. The results reveal that coding games can foster seven core science inquiry skills: arguing based on existing evidence, identifying problems, analyzing and interpreting data, evaluating and communicating, planning and conducting investigations, asking questions, and constructing explanations. This research recommends that more preschools integrate coding games into their learning activities, as they can effectively enhance children's science inquiry skills, which are essential for their future academic and professional success.

Keywords: coding game, early childhood, science inquiry skill

Article history

Received:	Revised:	Accepted:	Published:
08 May 2025	*06 July 2025*	*04 September 2025*	*05 October 2025*

Citation (APA Style): Munawar, M., Happy, N., Roshayanti, F., Setyoady, Y., & Luthfy, P. A. (2025). Developing science inquiry skills in early childhood through coding games. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 44*(3), pp.496-509. DOI https://doi.org/10.21831/cp.v44i3.85086

INTRODUCTION

In education, 21st-century skills not only equip children with academic knowledge but also encourage them to become innovative, productive, and responsible individuals, providing them with reasoning, programming, data literacy, problem-solving, and critical thinking skills to help them face challenges and rapid global changes (Kerdthaworn & Chaichomchuen, 2021; Lavi et al., 2021). Educators, corporations, and governments have emphasized the need for these skills, known as 21st-century competencies (Benbow et al., 2021; Vista, 2020), namely the 4Cs: critical thinking, creativity, collaboration, and communication (Almerich et al., 2020; Stauffer, 2021). Furthermore, educational systems worldwide are challenged to develop frameworks that emphasize the cultivation of skills, knowledge, and behaviors essential for success in the 21st century (Martinez, 2022).

A framework for visualizing the importance of educational experiences in science is inquiry-based science education. Key features of this framework include a) active involvement of students in the learning process with an emphasis on supporting knowledge with observations, experiences, or credible evidence; b) authentic and problem-based learning activities; c) consistent practice and development of systematic observation, question and answer, planning, and recording skills to obtain credible evidence; d) participation in collaborative group work, peer interaction, discursive argumentation, and communication with others as the main learning process; and e) development of autonomy and self-regulation through experience as essential objectives for learning (Constantinou et al., 2018). Inquiry-based learning combines science lessons with engaging tasks and tangible instruments, which eliminates the stiffness of conventional education and provides an engaging learning process that can develop students' science inquiry skills (Cheng et al., 2021). Skills that support the inquiry process are called inquiry skills (Pedaste, et al., 2015).

Science inquiry is an ideal approach to fostering young children's scientific understanding and research skills in discovering and applying new information to the challenges they encounter (Bevins & Price, 2016). Educators consider inquiry learning crucial for scientific learning and children's development (Constantinou et al., 2018) because, in learning science inquiry, there is a change in teachers' and students' roles in which teaching becomes more interactive and student-centered (Ramanathan et al., 2022; Williams et al., 2017). The objective of inquiry learning is to assist students in creating questions, discovering answers, or solving problems that fulfill their curiosity, as well as to help students comprehend a theory or concept about what they have studied (Gunawan et al., 2019). An inquiry-oriented approach offers a teaching strategy where students actively use scientific approaches for reasoning and making explanations about design, information, and evidence (Stender et al., 2018). Students learn how to process information scientifically, design investigations, evaluate evidence and information, and draw conclusions (van Uum et al., 2017). In the science inquiry learning process, it is expected that young children will not only regard inquiry as a learning method but will also gain and apply scientific knowledge through inquiry (Arnold et al., 2014). The fact that children are naturally inclined to explore, question, discover, analyze, create, and innovate makes it easier for them to adapt to the challenges of the 21st century (Tutkun, 2023). Additionally, if children are equipped with research and observation skills from preschool, they are more likely to experience high-quality science education (Bahar & Aksüt, 2020).

A learning model that suits the 21st century not only encompasses a scientific approach but also integrates the use of technology (Novitra et al., 2021). Inquiry-based learning that incorporates the use of technology is becoming more popular in science curricula around the world (Pedaste, Ma¨eots, et al., 2015). Therefore, this study employed coding games using educational robots. This activity was carried out while the children were exploring and playing (Dejonckheere et al., 2016), allowing them to enjoy the learning process through robotic coding games.

Robotic coding is beneficial for children because robotic coding can enhance their creativity, problem-solving ability, critical thinking, communication, collaboration, and decision-making skills (Arís & Orcos, 2019; Coşkunserçe, 2021; Guven et al., 2022). Coding encompasses a wide range of fundamental mathematical, scientific, and communication skills (Lee, 2020). Coding can be taught to children from an early age (Bers, 2019) to promote their conceptual and creative skills and provide a strong foundation for critical and technical competencies (Monteiro et al., 2021). Additionally, coding provides children with valuable intellectual structures (Su et al., 2023).

Recent studies reveal that learning coding in early years has positive impacts on behavior, knowledge, and skills in various areas such as problem-solving, computational thinking, and mathematical reasoning skills (Bers et al., 2014; Çankaya et al., 2017; Somuncu & Aslan, 2022; Sullivan & Bers, 2016). Many researchers also state that coding in early childhood is not just a technical skill but a new form of literacy and self-expression essential for mastering 21st-century competencies (Resnick, 2017). Thus, early childhood educators need to provide children with authentic, engaging experiences related to coding. his can begin with familiar daily routines or experiences, helping children develop habits of coding and independent exploration (Lee, 2020). Therefore, in this study, the coding robots used were equipped with storybooks and themed carpets corresponding to the stories, such as morning routines, social interactions, transportation activities, and ecological conservation. These coding games are not only integrated with children's daily activities but also introduce new knowledge and environmental awareness.

Morning routines typically include bathing, having breakfast, cleaning the house, and other daily tasks. Activities in the social environment include things that should be done in playgrounds, restaurants, malls, shops, and pharmacies. Public transportation activities include rules that must be followed at bus terminals, buses, gas stations, airports, and train stations. Plant and environmental conservation activities discuss plant and ecological problems and how to maintain plant and environmental sustainability.

Although scientific inquiry has become one of the most effective methodologies for learning science, research focusing on preschool-aged children remains limited (Zudaire et al., 2022). In addition, Eti & Sigirtmac (2021) suggest that future research focuses on the development of science inquiry achieved by children. Therefore, the current research addresses this gap by examining the development of children's scientific inquiry skills. His research differs from previous studies that focused primarily on developing computational thinking in preschoolers through coding games (Critten et al., 2022). Instead, this study explores how coding games can be used to develop scientific inquiry skills, thereby supporting the formation of a generation equipped with 21st-century competencies.

METHOD

A qualitative descriptive research design was used in this study to comprehensively explore science inquiry skills in early childhood that are developed by using coding games. Research respondents were selected using a purposive sampling technique. The criteria for research respondents in this study were a) kindergarten class B children aged 5-6 years; b) located in Semarang, Central Java, Indonesia; and c) the school was registered with the Indonesian Kindergarten Teachers Association (IGTKI). The respondents of this research were 16 kindergarten schools, with four students and one teacher at each school. In collecting data, researchers directly visited the research locations to observe children playing coding using robots in class, interviewed the teachers regarding the research focus, and documented the activities. In collecting data, code was used for each child, namely C1, C2, and so on, and for each kindergarten, the code used was P1, P2, and so on. Before conducting the research, researchers obtained informed consent from the principals of each kindergarten.

During the observation, researchers recorded the observation using mobile devices. Regarding the interview, researchers used a semi-structured interview. Researchers interviewed teachers one by one after class hours were over. For the data analysis, researchers used NVivo 12 software, a qualitative data analysis program that helps researchers organize, code, and analyze qualitative data such as interviews, text, audio, video, and images.

FINDINGS AND DISCUSSION

Findings

This research reveals that coding games can develop seven primary science inquiry skills: arguing based on existing evidence, identifying problems, analyzing and interpreting data, evaluating and communicating findings, planning and conducting investigations, asking questions, and constructing explanations.

In this coding game, children perform coding activities to predict the destination, route, and the number of steps the robot must take to reach its destination by pressing the remote on an Android cellphone. The teacher reads a story, and then the child moves the robot on the themed carpet, according to the storyline read by the teacher, using the remote on the cellphone screen (see Figure 1 & 2). If the remote is pressed once, the robot moves one step on the carpet; if the remote is pressed twice, the robot moves two steps; if the remote is pressed three times, it moves three steps, and so on. If the child presses the up arrow, the robot moves forward; if the down arrow is pressed, the robot moves backward; if the right arrow is pressed, the robot turns right; if the left arrow is pressed, the robot moves left; and if the 45-degree arrow is pressed, tilted arrow to the right or left, the robot turns slightly in that direction.

In addition to being based on the story read by the teacher, children also get the opportunity to operate the robot freely, exploring various destinations available on the carpet. During this learning process, children show great enthusiasm because the use of coding robots provides innovative, engaging, and practical learning media that connect with real-life contexts. Through this themed robot game, children and teachers explore various daily activities, both at home and in social environments.

Figure 1. A Child Moved the Robot by Pressing the Buttons on the Cellphone Screen, according to the Story Read by the Teacher

Figure 2. Two Children Collaborated, Moving Robots to Explore Places on the Carpet according to Their Own Will

Coding that children do while playing with robots in this study are: a) children learn how to turn robots on and off; b) children learn the function of buttons on a cell phone to move the robot; c) children learn the symbols on the carpet where the robot moves; d) children learn that robots must do activities in sequence according to the story read by the teacher; e) children operate the robot by pressing the remote buttons so that the robot performs activities according to the sequence of the story, breaking down each activity into smaller steps (e.g., when the remote is pressed once, the robot moves one step; when pressed twice, it moves two steps, and so on); f) children learn fundamental control structures, for example cause and effect, which emerge as they use the remote to move the robot forward, backward, right, left, and diagonally; g) children learn specific programming instructions that are in accordance with the programming language of their choice, namely: children move the robot to rotate at an angle (45 degrees) so that the robot moves according to its destination; h) children build simple programs using easy cause and effect orders, namely: children press the up arrow and the robot moves forward, children press the down arrow and the robot moves backward, children press the right arrow and the robot turns right, children press the left arrow and the robot moves left, children press the 45 degree tilted arrow to the right or left and the robot turns slightly to the right and/or left; i) children make plans, execute them, and refine those plans to ensure the robot reaches its intended goal; and j) children identify and correct errors in their coding sequences, for instance, when children move the robot in the wrong direction or not according to the target, then children will correct the arrow code used on the remote. While playing this game, children's behavior shows science inquiry skills, as seen in Table 1 (Appendix 1).

Discussion

The In this study, the coding stages done by children were in line with previous research done by Bers (2019), as seen in Table 2.

Table 2. Comparison of coding stages in this research with previous research

Coding and decoding stages for children (Bers, 2019)	Coding that children do while playing with robots in this study
Learning interface concepts (e.g., on and off)	Children learn how to turn robots on and off.
Learning a limited set of symbols (syntax) and grammar rules in a programming language	Children learn the function of buttons on a cell phone to move the robot. Children learn the symbols on the carpet where the robot moves. Children learn that robots must do activities in sequence according to the story read by the teacher. Children operate the robot by pressing the remote button so that the robot performs activities according to the sequence of the story read by the teacher, in which the child breaks down each activity into small steps; if the remote is pressed once, then the robot will move one box on the carpet; if the remote is pressed twice, then the robot will move 2 boxes on the carpet, and so on.
Understanding that sequencing matters and that different orders (symbols) put together result in different behaviors	Children learn basic control structures, such as cause and effect, which emerge as they use the remote to move the robot forward, backward, right, left, and diagonally. Children learn specific instructions for programs that are in accordance with the programming language of their choice; namely, children move the robot to rotate at an angle (45°) so that the robot moves according to its destination. Children create simple programs with simple cause-and-effect commands; namely, children press the up arrow and the robot moves forward, children press the down arrow and the robot moves backward, children press the right arrow and the robot turns right, children press the left arrow and the robot moves left, and children press the 45-degree tilted arrow to the right or left and the robot turns slightly to the right and/or left.
Learning how to do simple debugging by trial and error	Children make plans, then run the robot according to the plans they make, and debug errors so that the robot runs according to its purpose. Children identify and correct grammatical errors in the code; namely, when children move the robot in the wrong direction or not according to the target, then children will correct the arrow code used on the remote.

The science inquiry skills that were develop in this study are in line with previous research done by Lou, et al. (2015) and Örnek & Alaam (2024), as seen in Table 3.

Table 3. Comparison of science inquiry skills developed in this study with previous research

Science Inquiry Skills (Lou, et al., 2015)	Science Inquiry Skills (Örnek & Alaam, 2024)	Science Inquiry Skills in this Research
Identifying questions	Engaging students with questions	Asking questions
Planning	Answering questions using evidence	Identifying problems
Collecting data	Formulating explanations from evidence	Planning and conducting investigations
Analyzing and describing data	Connecting explanations to scientific knowledge	Arguing based on the existing evidence
Explaining results and drawing conclusions		
Recognizing alternative explanations and predictions	Communicating and providing explanations	Analyzing and interpreting data
		Evaluating and communicating
		Constructing explanations

Asking questions

By posing questions, children can get the information they need from their surroundings, select who they ask questions to, ask about invisible things, talk about abstract ideas or feelings, and draw attention to features of the same thing (Ruggeri et al., 2021). In addition, asking questions to seek information effectively is essential for preschoolers' independent learning (Ruggeri & Lombrozo, 2019). The skill of asking questions demonstrates that children's coordination of complex cognitive skills enables them to initiate and direct pedagogical exchanges and serves as a stimulus for them to learn from others (Ronfard et al., 2018). This is consistent with the findings of preschoolers in the US and UK, which highlight the importance of children asking questions as a tool for learning from others (Ünlütabak et al., 2019).

In this study, skill in asking questions was shown by children paying attention, wondering, and asking questions about the material when teachers gave information about robots.

Identifying problems

Through problems, students can evaluate and refine the efficacy of their understanding, reasoning, and approach to solving problems. It is believed that when students engage in complex and ill-defined problems, their discussions and problem-solving processes become more sophisticated, promoting creativity, reasoning, and evidence-based solutions (Kim & Pegg, 2019).

Identifying a problem is the initial step in solving a problem. When this stage is carried out correctly, potential and effective solutions are more likely to emerge (Kember, 2018). Problem identification has a crucial role because it has the following functions: a) Foundation for problem-solving: identifying the problem is the foundation on which effective problem-solving is built. Without recognizing the existence of a problem and understanding its nature, it is difficult to find potential solutions; b) Focus and direction: Identifying a problem provides focus and direction in the problem-solving process. It clarifies what needs to be addressed and helps individuals or teams avoid wasting time and resources on unrelated matters; c) Prevention: identifying problems early can prevent them from becoming large and complex; d) Efficiency: identifying problems efficiently simplifies the problem-solving process. When the real problem is identified, it is easy to find the most appropriate and efficient solution; e) Informed decision-making: identifying problems facilitates making the right decisions. It allows individuals or teams to gather relevant information, assess potential solutions, and make informed choices; f) Continuous improvement: in many aspects of life, identifying problems is the first step towards continuous improvement; g) Gaving time and resources: failing to identify problems can result in wasting time and resources on ineffective solutions or even making the problem worse. Early recognition can prevent such inefficiencies; and h) Learning opportunities: identifying problems provides valuable learning opportunities. This encourages individuals to think critically, seek information, and engage in problem-solving exercises, as well as encourages personal growth and development (Mustapha, 2023).

In this study, problem-identification skills were demonstrated by students being able to (a) build structures and design solutions to address challenges in the game,, (b) recognize aspects that required repair or improvement, (c) discuss possible solutions or ideas that could make something work better, and (d) observe the properties of objects and materials to understand how they work

Planning and conducting investigations

Planning an investigation is considered a higher-order thinking skill that relies on students' ability to think ahead (such as predictive reasoning) and to visualize the steps needed to solve a problem (Macmillan Education, 2019). When students actively participate in planning and carrying out investigations, they learn through experience which strategies are effective, and which are not (Duschl & Bybee, 2014).

In this study, the skills of planning and conducting investigations were demonstrated by children who can: (a) generate new ideas for exploration, (b) engage in a fearless exploration of the environment as children move the robot around the places in the story, based on their own will, (c) investigate through trial and error, such as children being able to change coordinates when they feel the direction is not right, and (d) ask predictive questions such as "What will happen if ...?"

Arguing based on existing evidence

The literature has consistently shown that children possess the ability to argue from an early age (Rapanta et al., 2025). Argumentative skills include constructing arguments, confutation, and counterarguments (Rapanta, 2019). These skills help students evaluate the information critically, enabling them to make informed and evidence-based decisions (Noroozi et al., 2020; Songsil et al., 2019). During argumentation, students are expected to present claims supported by relevant evidence and logical reasoning (Jumadi et al., 2021; Ping et al., 2020). Furthermore, argumentation is a fundamental component of critical thinking (Davies, 2015). When students think critically, they provide reasoned arguments that support their beliefs or conclusions (Rosidin et al., 2019). Critical thinking, in turn, is regarded as essential for success in modern, technologically advanced, and information-rich societies (Murphy et al., 2016).

Analyzing and interpreting data

Understanding, identifying, and avoiding inaccurate information is essential during the learning process. Therefore, children need to be equipped with the ability to analyze and interpret information accurately so that they are not easily misguided (Brosseau-Liard, 2017). This aligns with the findings of Pols et al. (2021), click or tap here to enter text. which revealed that students require structures guidance to enhance their analytical and data interpretation of data skills, as they often face challenges in these areas.

To effectively use data, students must be able to: a) identify variation, such as objects that vary in size, weight, color, use, attractiveness; activities that vary according to who takes part and what is achieved; and human characteristics such as height, opinions, and roles; b) classify information, for example by color, function (objects with spouts are good for pouring, objects with lids are good for storing), taste (my favorite drink is milk); shape (pencils, ballpoint pens, markers are writing tools but have different shapes), form (triangle, square, circle), etc.; and c) sorting information: objects are classified into stacks, plants are divided into fruiting and non-fruiting plants by stating the criteria for each (Platas, 2023).

The results of this study indicate that children’s data analysis and interpretation skills were demonstrated when they were able to: (a) share experiences and observations with others, (b) identify and predict changes in natural or artificial phenomena, and (c) recognize and describe similarities and differences between objects, while also providing logical reasons or evidence to support their observations.

Evaluating and communicating

Children are active social learners who analyze and evaluate the meaning of evidence according to the evidence’s source (Gweon, 2021). Recent research also indicates that children can assess the plausibility of a claim even when limited evidence is available (Butler et al., 2018). Moreover, communication skills are a process needed to apply knowledge construction and problem-solving in the real world successfully (Stehle & Peters-Burton, 2019). Effective communication involves connecting ideas or products to the needs and perspectives of others (Warin et al., 2016) and requires students to choose appropriate media and tailor their messages according to the audience (van Laar et al., 2017).

In this study, the skill in evaluating and communicating is demonstrated by students being able to (a) document their identification results and share information about object or materials; (b) compare objects, structures, systems, and living things; (c) articulate similarities and differences, such as recognizing that trees consist of different parts, namely roots, trunks, branches, and leaves; (d) answer and ask questions; and (e) discuss their investigative findings collaboratively.

Constructing Explanation

Children's skill in constructing explanations plays a crucial role in learning (Legare, 2014; Legare & Gelman, 2014). Research conducted by Legare & Lombrozo (2014) shows that explanations are an effective mechanism for supporting causal learning in early childhood, as it directs children’s attention toward causal mechanisms and promotes the formation of generalizations. Constructing sound scientific explanations helps students develop scientific literacy and reasoning abilities (Moore & Wright, 2023). Developing scientific explanations requires integrating several skills, such as generating ideas, organizing reasoning, and expressing arguments clearly (Graham et al., 2020). The fundamental goal of a constructed scientific explanation is to answer "why" or "how" questions (Federer et al., 2015). In this study, the skill of constructing explanations was demonstrated when children shared ideas with their peers about why and how certain phenomena occurred, showing their ability to reason casually and collaboratively.

CONCLUSION

Researchers studied science inquiry skills in early childhood through coding games using robots. This study has a positive impact on children's scientific thinking and inquiry abilities. Specifically, coding activities were found to develop seven core science inquiry skills, namely: arguing based on existing evidence, identifying problems, analyzing and interpreting data, evaluating and communicating, planning and conducting investigations, asking questions, and building explanations. Furthermore, this study raises awareness that the integration of robotics in coding activities not only enhances children's inquiry-based science learning but also introduces innovative and enjoyable learning experiences that are easily embraced by young learners. Future research is recommended to explore other potential benefits of coding games for early childhood development, particularly in a broader educational and developmental context.

ACKNOWLEDGMENTS

The researchers would like to thank the school, the Indonesian Kindergarten Teachers Association (IGTKI) of Central Java Province, and the Pena Prima research laboratory of Universitas PGRI Semarang for their valuable assistance in this research.

REFERENCES

Almerich, G., Suárez-Rodríguez, J., Díaz-García, I., & Cebrián-Cifuentes, S. (2020). 21st-century competences: The relation of ICT competences with higher-order thinking capacities and teamwork competences in university students. *Journal of Computer Assisted Learning*, *36*(4), pp. 468–479. DOI: https://doi.org/10.1111/jcal.12413

Arís, N., & Orcos, L. (2019). Educational robotics in the stage of secondary education: Empirical study on motivation and STEM skills. *Education Sciences*, *9*(2), p. 73. DOI: https://doi.org/10.3390/educsci9020073

Arnold, J. C., Kremer, K., & Mayer, J. (2014). Understanding students' experiments—What kind of support do they need in inquiry tasks? *International Journal of Science Education*, *36*(16), pp. 2719–2749. https://doi.org/https://doi.org/10.1080/09500693.2014.930209

Bahar, M., & Aksüt, P. (2020). Investigation on the effects of activity-based science teaching practices in the acquisition of problem-solving skills for 5–6-year-old pre-school children. *Journal of Turkish Science Education*, *17*(1), pp. 22–39. DOI: https://doi.org/10.36681/tused.2020.11

Benbow, R. J., Lee, C., & Hora, M. T. (2021). Exploring college faculty development in 21st-century skill instruction: an analysis of teaching-focused personal networks. *Journal of Further and Higher Education*, *45*(6). https://doi.org/10.1080/0309877X.2020.1826032

Bers, M. U. (2019). Coding as another language: a pedagogical approach for teaching computer science in early childhood. *Journal of Computers in Education*, *6*(4). DOI: https://doi.org/10.1007/s40692-019-00147-3

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers and Education*, *72*, pp. 145–157. DOI: https://doi.org/10.1016/j.compedu.2013.10.020

Bevins, S., & Price, G. (2016). Reconceptualising inquiry in science education. *International Journal of Science Education*, *38*(1), pp. 17–29. DOI: https://doi.org/https://doi.org/10.1080/09500693.2015.1124300

Brosseau-Liard, P. E. (2017). The roots of critical thinking: Selective learning strategies in childhood and their implications. *Canadian Psychology*, *58*(3). DOI: https://doi.org/10.1037/cap0000114

Butler, L. P., Schmidt, M. F. H., Tavassolie, N. S., & Gibbs, H. M. (2018). Children's evaluation of verified and unverified claims. *Journal of Experimental Child Psychology*, *176*. DOI: https://doi.org/10.1016/j.jecp.2018.07.007

Çankaya, S., Durak, G., & Yünkül, E. (2017). Robotlarla Programlama Eğitimi: Öğrencilerin Deneyimlerinin ve Görüşlerinin İncelenmesi. *Turkish Online Journal of Qualitative Inquiry*, *8*(4), pp. 428–445

Cheng, M., Su, C. Y., & Kinshuk, C. Y. (2021). Integrating smartphone-controlled paper airplane into gamified science inquiry for junior high school students. *Journal of Educational Computing Research*, *59*(1), pp. 71–94. DOI: https://doi.org/10.1177/0735633120953598

Constantinou, C. P., Tsivitanidou, O. E., & Rybska, E. (2018). What is inquiry-based science teaching and learning? In O. Tsivitanidou, P. Gray, E. Rybska, L. Louca, & C. Constantinou (Eds.), *Professional development for inquiry-based science teaching and learning. Contributions from Science Education Research* (Vol. 5, pp. 1–23). Springer, Cham. DOI: https://doi.org/https://doi.org/10.1007/978-3-319-91406-0_1

Coşkunserçe, O. (2021). Implementing teacher-centered robotics activities in science lessons: The effect on motivation, satisfaction and science skills. *Journal of Pedagogical Research*, *5*(1), pp. 50–64. DOI: https://doi.org/10.33902/JPR.2021067231

Critten, V., Hagon, H., & Messer, D. (2022). Can pre-school children learn programming and coding through guided play activities? A case study in computational thinking. *Early Childhood Education Journal*, *50*(6). DOI: https://doi.org/10.1007/s10643-021-01236-8

Davies, M. (2015). A model of critical thinking in higher education. In *Higher education: Handbook of theory and research* (M.B. Paulsen, pp. 41–92). Springer. DOI: https://doi.org/10.1007/978-3-319-12835-1_2

Dejonckheere, P. J. N., De Wit, N., Van de Keere, K., & Vervaet, S. (2016). Exploring the classroom: Teaching science in early childhood. *International Electronic Journal of Elementary Education*, *8*(4), pp. 537–558. DOI: https://doi.org/10.12973/eu-jer.5.3.149

Duschl, R. A., & Bybee, R. W. (2014). Planning and carrying out investigations: an entry to learning and to teaching professional development around NGSS science and engineering practices. *International Journal of STEM Education*, *1*(12). DOI: https://doi.org/10.1186/s40594-014-0012-6

Eti, I., & Sigirtmac, A. (2021). Developing inquiry-based science activities in early childhood education: An action research. *International Journal of Science Education*, *7*(3), pp. 785–804. DOI: https://doi.org/https://doi.org/10.46328/ijres.1973

Federer, M. R., Nehm, R. H., Opfer, J. E., & Pearl, D. (2015). Using a constructed-response instrument to explore the effects of item position and item features on the assessment of students' written scientific explanations. *Research in Science Education*, *45*(4). DOI: https://doi.org/10.1007/s11165-014-9435-9

Graham, S., Kiuhara, S. A., & MacKay, M. (2020). The effects of writing on learning in science, social studies, and mathematics: A meta-analysis. *Review of Educational Research*, *90*(2). DOI: https://doi.org/10.3102/0034654320914744

Gunawan, Harjono, A., Hermansyah, & Herayanti, L. (2019). Guided inquiry model through virtual laboratory to enhance students' science process skills on heat concept. *Cakrawala Pendidikan*, *38*(2). DOI: https://doi.org/10.21831/cp.v38i2.23345

Guven, G., Kozcu Cakir, N., Sulun, Y., Cetin, G., & Guven, E. (2022). Arduino-assisted robotics coding applications integrated into the 5E learning model in science teaching. *Journal of Research on Technology in Education*, *54*(1), pp. 108–126. DOI: https://doi.org/10.1080/15391523.2020.1812136

Gweon, H. (2021). Inferential social learning: cognitive foundations of human social learning and teaching. In *Trends in Cognitive Sciences, 25*(10). DOI: https://doi.org/10.1016/j.tics.2021.07.008

Jumadi, J., Perdana, R., Riwayani, & Rosana, D. (2021). The impact of problem-based learning with argument mapping and online laboratory on scientific argumentation skill. *International Journal of Evaluation and Research in Education*, *10*(1). DOI: https://doi.org/10.11591/ijere.v10i1.20593

Kember, J. (2018). *Problem identification: The first important step in problem solving*. https://www.renaissance.com/2018/01/18/blog-problem-identification-the-first-important-step-in-problem-solving/#blog-main-header-3

Kerdthaworn, P., & Chaichomchuen, S. (2021). A Learning model of STEM Education on cloud computing technology, to promote learning and innovation skills for students practicing teachers. *Journal of Physics: Conference Series*, *1835*(1). DOI: https://doi.org/10.1088/1742-6596/1835/1/012073

Kim, M., & Pegg, J. (2019). Case analysis of children's reasoning in problem-solving process. *International Journal of Science Education*, *41*(6), pp. 739–758. DOI: https://doi.org/10.1080/09500693.2019.1579391

Lavi, R., Tal, M., & Dori, Y. J. (2021). Perceptions of STEM alumni and students on developing 21st century skills through methods of teaching and learning. *Studies in Educational Evaluation*, *70*. DOI: https://doi.org/10.1016/j.stueduc.2021.101002

Lee, J. (2020). Coding in early childhood. *Contemporary Issues in Early Childhood*, *21*(3), pp. 266–269. DOI: https://doi.org/https://doi.org/10.1177/1463949119846541

Legare, C. H. (2014). The contributions of explanation and exploration to children's scientific reasoning. *Child Development Perspectives*, *8*(2), pp. 101–106. DOI: https://doi.org/10.1111/cdep.12070

Legare, C. H., & Gelman, S. A. (2014). Examining explanatory biases in young children's biological reasoning. *Journal of Cognition and Development*, *15*(2), pp. 287–303. DOI: https://doi.org/10.1080/15248372.2012.749480

Legare, C. H., & Lombrozo, T. (2014). Selective effects of explanation on learning during early childhood. *Journal of Experimental Child Psychology*, *126*, pp. 189–212. DOI: https://doi.org/10.1016/j.jecp.2014.03.001

Lou, Y., Blanchard, P., & Kennedy, E. (2015). Development and validation of a science inquiry skills assessment. *Journal of Geoscience Education*, *63*(1). DOI: https://doi.org/10.5408/14-028.1

Macmillan Education. (2019). *Developing planning skills in scientific enquiries*. https://www.macmillanic.com/developing-planning-skills-in-scientific-enquiries/

Martinez, C. (2022). Developing 21st century teaching skills: A case study of teaching and learning through project-based curriculum. *Cogent Education*, *9*(1). DOI: https://doi.org/10.1080/2331186X.2021.2024936

Monteiro, A. F., Miranda-Pinto, M., & Osório, A. J. (2021). Coding as literacy in preschool: A case study. *Education Sciences*, *11*(5), p. 198. DOI: https://doi.org/https://doi.org/10.3390/educsci11050198

Moore, B. A., & Wright, J. (2023). Constructing written scientific explanations: a conceptual analysis supporting diverse and exceptional middle- and high-school students in developing science disciplinary literacy. *Frontiers in Education*, *8*. DOI: https://doi.org/10.3389/feduc.2023.1305464

Murphy, P. K., Firetto, C. M., Wei, L., Li, M., & Croninger, R. M. V. (2016). What really works: Optimizing classroom discussions to promote comprehension and critical-analytic thinking. *Policy Insights from the Behavioral and Brain Sciences*, *3*(1), pp. 27–35. DOI: https://doi.org/10.1177/2372732215624215

Mustapha, A. (2023). *Empowering young problem solvers: Teaching kids how to identify and tackle challenges*. https://www.linkedin.com/pulse/empowering-young-problem-solvers-teaching-kids-how-tackle-mustapha

Noroozi, O., Dehghanzadeh, H., & Talaee, E. (2020). A systematic review on the impacts of game-based learning on argumentation skills. In *Entertainment Computing, 35*. DOI: https://doi.org/10.1016/j.entcom.2020.100369

Novitra, F., Festiyed, Yohandri, & Asrizal. (2021). Development of online-based inquiry learning model to improve 21st-century skills of physics students in senior high school. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(9). DOI: https://doi.org/10.29333/ejmste/11152

Örnek, F., & Alaam, S. (2024). Five essential features of scientific inquiry in Bahraini primary school science textbooks and workbooks. *Science & Education*. DOI: https://doi.org/10.1007/s11191-024-00523-1

Pedaste, M., Ma¨eots, M., Siiman, L. A., de Jong, T., Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: definitions and the inquiry cycle. *Educational Research Review*, *14*, pp. 47–61. DOI: https://doi.org/https://doi.org/10.1016/j.edurev.2015.02.003.

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: definitions and the inquiry cycle. *Educational Research Review, 14*. DOI: https://doi.org/10.1016/j.edurev.2015.02.003

Ping, I. L. L., Halim, L., & Osman, K. (2020). Explicit teaching scientific argumentation as an approach in developing argumentation skills, science process skills and biology understanding. *Journal of Baltic Science Education*, *19*(2). DOI: https://doi.org/10.33225/jbse/20.19.276

Platas, L. M. (2023). *What children know and need to know about data.* https://prek-math-te.stanford.edu/measurement-data/what-children-know-and-need-know-about-data

Pols, C. F. J., Dekkers, P. J. J. M., & de Vries, M. J. (2021). What do they know? Investigating students' ability to analyse experimental data in secondary physics education. *International Journal of Science Education*, *43*(2). https://doi.org/10.1080/09500693.2020.1865588

Ramanathan, G., Carter, D., & Wenner, J. (2022). A framework for scientific inquiry in preschool. *Early Childhood Education Journal*, *50*(7), pp. 1263–1277. DOI: https://doi.org/10.1007/s10643-021-01259-1

Rapanta, C. (2019). *Argumentation strategies in the classroom*. Vernon Press

Rapanta, C., Macagno, F., & Jenset, G. (2025). A close look at children's and adolescents' arguments: combining a developmental, educational, and philosophical perspective. *European Journal of Psychology of Education*, *40*(1), p. 3. DOI: https://doi.org/10.1007/s10212-024-00914-6

Resnick, M. (2017). *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play*. The MIT Press. https://doi.org/10.7551/mitpress/11017.001.0001

Ronfard, S., Zambrana, I. M., Hermansen, T. K., & Kelemen, D. (2018). Question-asking in childhood: A review of the literature and a framework for understanding its development. *Developmental Review, 49*, pp. 101–120. DOI: https://doi.org/10.1016/j.dr.2018.05.002

Rosidin, U., Kadaritna, N., & Hasnunidah, N. (2019). Can argument-driven inquiry models have impact on critical thinking skills for students with different personality types? *Cakrawala Pendidikan*, *38*(3). DOI: https://doi.org/10.21831/cp.v38i3.24725

Ruggeri, A., Walker, C. M., Lombrozo, T., & Gopnik, A. (2021). How to help young children ask better questions? *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.586819

Ruggeri, A., Xu, F., & Lombrozo, T. (2019). Effects of explanation on children's question asking. *Cognition*, *191*. DOI: https://doi.org/10.1016/j.cognition.2019.05.003

Somuncu, B., & Aslan, D. (2022). Effect of coding activities on preschool children's mathematical reasoning skills. *Education and Information Technologies*, *27*(1), pp. 877–890. DOI: https://doi.org/10.1007/s10639-021-10618-9

Songsil, W., Pongsophon, P., Boonsoong, B., & Clarke, A. (2019). Developing scientific argumentation strategies using revised argument-driven inquiry (rADI) in science classrooms in Thailand. *Asia-Pacific Science Education*, *5*(1). DOI: https://doi.org/10.1186/s41029-019-0035-x

Stauffer, B. (2021). *What are the 4 C's of 21st century skills?* https://www.icevonline.com/blog/four-cs-21st-century-skills

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st-century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, *6*(39). https://doi.org/10.1186/s40594-019-0192-1

Stender, A., Schwichow, M., Zimmerman, C., & Härtig, H. (2018). Making inquiry-based science learning visible: The influence of CVS and cognitive skills on content knowledge learning in guided inquiry. *International Journal of Science Education*, *40*(15). DOI: https://doi.org/10.1080/09500693.2018.1504346

Su, J., Yang, W., & Li, H. (2023). A scoping review of studies on coding curriculum in early childhood: investigating its design, implementation, and evaluation. *Journal of Research in Childhood Education*, *37*(2), pp. 341–361. DOI: https://doi.org/10.1080/02568543.2022.2097349

Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International Journal of Technology and Design Education*, *26*(1), pp. 3–20. DOI: https://doi.org/10.1007/s10798-015-9304-5

Tutkun, C. (2023). 21st century skills in early childhood/erken cocuklukta 21. Yuzyil becerileri. In *Education & Science* (2nd ed., pp. 7–24). Efe Akademik Publishing. https://doi.org/10.59617/efepub20239

Ünlütabak, B., Nicolopoulou, A., & Aksu-Koç, A. (2019). Questions asked by Turkish preschoolers from middle-SES and low-SES families. *Cognitive Development*, *52*. DOI: https://doi.org/10.1016/j.cogdev.2019.100802

van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior*, *77*, pp. 577–588. DOI: https://doi.org/10.1016/j.chb.2017.03.010

van Uum, M. S. J., Verhoeff, R. P., & Peeters, M. (2017). Inquiry-based science education: scaffolding pupils' self-directed learning in open inquiry. *International Journal of Science Education*, *39*(18). DOI: https://doi.org/10.1080/09500693.2017.1388940

Vista, A. (2020). Data-driven identification of skills for the future: 21st-century skills for the 21st-century workforce. *SAGE Open*, *10*(2). DOI: https://doi.org/10.1177/2158244020915904

Warin, B., Talbi, O., Kolski, C., & Hoogstoel, F. (2016). Multi-Role Project (MRP): A New Project-Based Learning Method for STEM. *IEEE Transactions on Education*, *59*(2), pp. 137–146. DOI: https://doi.org/10.1109/TE.2015.2462809

Williams, P. J., Nguyen, N., & Mangan, J. (2017). Using technology to support science inquiry learning. *Journal of Technology and Science Education*, *7*(1), p. 26. DOI: https://doi.org/10.3926/jotse.234

Zudaire, I., Buil, R., Uriz, I., & Napal, M. (2022). Mars explorers: A science inquiry-based learning project in preschool. *International Journal of Early Childhood*, *54*(2), pp. 297–320. DOI: https://doi.org/10.1007/s13158-021-00308-5

Appendix 1

Table 1. Children's behavior that deminstrates science inquiry skills while playing with robotic coding

Science Inquiry skills, which develop when children learned to code through robots in this study	The most frequently occurring indicators in this study demonstrate science inquiry skills.	Children's conversations while learning to code through robots in this study demonstrate science inquiry skills
Asking questions	Children pay attention, show curiosity, and ask questions about robots when teachers give information about the robots.	C1: "What toys are those, Miss?" C5: "Can they move?" C6: "How to run them?" C10: "How to stop them?" C17: "The robots are cute. What kind of robots are they, Miss?"
Identifying problems	Children design and build solutions to solve problems in the game.	C5: "The robot is walking too far; move back."
	Children recognize things that need improvement or repair	C4: "The forest is dirty; there is a lot of rubbish." C22: "The river is so dirty."
	Children discuss possible solutions or ideas about what might make something work better.	C7: "Come on, let's pick up the trash and put it in the trash can." C25: "Let's go to the factory so the waste isn't dumped into the river."
	Children observe object properties and discover how they work.	C1: "My robot won't turn." C3 responds to C1's problem while pointing to the cellphone screen and saying, "Press this button to turn."
Planning and conducting investigations	Children generate new ideas for exploration.	C7: "After sweeping and mopping, what's next?"
	Children engage in fearless exploration of the environment as they move the robot around the places in the story, based on their own will.	C20: "Miss, I want to play at Fluffy's house; I want to take Fluffy to the park. C3: "I want to move the robot back first, then I want to go to the forest."
	Children investigate through trial and error as they operate buttons on an android phone along a map.	C48: "…Well, it's a dead end…. I'll look for another way... I want to go there... not here."
	Children ask questions such as "What would happen if..."	C1: "If this button is pressed, what will the robot do? C9: "If the trash is left unattended, what will happen to the park?
Arguing based on the existing evidence	Children recognize and articulate observations and data.	C7: "I want to go this way; it's easier." C31: I want to take the bus; I'll buy a ticket first." C11: "Oh, the river is dirty because of the waste from the factory."
	Children identify attributes or characteristics of objects/materials.	C27: "The plane's departure gate is there." C16: "Don't put the towel down; there's a clothesline. Put it there."
Analyzing and interpreting data	Children explain ideas, make predictions, and tell differences about weather, animal behavior, seasonal changes, and other natural phenomena based on experience or prior knowledge.	C3: "Don't go past the river; you'll fall in. Just go this way." C14: "The river is really dirty; poor fish, they could die."
Evaluating and communicating	Children identify and predict changes in things/phenomena (natural/artificial)	C32: "Why are all the trees being cut down...it's hot." C55: "If it's like this, it'll flood."
	Children recognize and describe similarities and differences between objects and can provide reasons/evidence.	C40: "Supermarkets are smaller than malls." C42: "Supermarkets are smaller than malls."
	Children document their findings and share information about objects/materials.	C50: "If you shop at the mall, just bring a cloth bag, because using a plastic bag can damage the environment."

	Children compare and articulate similarities and differences among objects, systems, or living things, e.g., parts of a tree such as roots, trunks, branches, and leaves.	C60: “Trees have big roots, tall trunks, and lots of leaves.”
Constructing explanation	Children answer and ask questions.	C44: “Why can't it be with the yellow one?"
	Children discuss about investigations.	C33: “The river is so dirty; why is that?”
	Children share ideas with peers about why and how things happen.	C22: “Oops, it fell in. Oops, it fell in again. It walked on the sea?” C15: “You know, there's a factory there; the waste is dumped into this river. That's why the river is dirty.”