Developing Educational Toy for Enhancing Elementary Students' Computational Thinking Skills by Using Design Thinking Process

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Abstract

Computational thinking is a skill of the 21st century which becoming extremely important in the world of rapid growth technology. Previous studies found that the younger children learn the skills, the easier they can apply them in future education. Various virtual instructional tools were created to improve children's Computational Thinking skills. However, interacting with physical toys will make younger kids learn more actively. In this research, to fully develop the computational instrument, we created it under the design thinking process. We started to empathize and study the computational thinking framework, educational technology toy concepts and creations, active learning for elementary students, and educational psychology. Then we defined and ideated ideas. Afterward, we designed a virtual prototype and collected feedback. Subsequently, we selected the most suitable hardware and developed the toy. The result indicates that the hybrid toy with both virtual and physical sections is preferable by having a virtual part as a commander and a physical part as a demonstrator. The core structure of the toy consists of 3 parts. First, the controlling hardware was a programmable microcontroller that can be coded in a block-based style via an electronics device. Second, the motion hardware we selected is called "Mecanum Wheels." Lastly, the outer case was a 3D printing cat model. This study shows the hybrid educational toy development that can enhance elementary students' Computational Thinking skills. In further research, we aim to implement our computational thinking toy in the elementary class and conduct experimental research regarding Computational Thinking skills improvement.

Keywords: Coding, Early Childhood, Educational Technology, Problem Solving, Programming

1. Introduction

Amid the rapid growth of technology trends, the world is changing rapidly. When changes occur, adjustments are needed to reflect the progress that has been made. One of the important things that have changed dramatically from the technology disruption is studying, working, and living skills which are referred to as "21st-Century Skills."

The key to learning that can lead to the development of 21st-century skills is learning the principles of Computational Thinking. The computational Thinking Concept refers to the process of problem-solving and systematic thinking which can be divided into 3 parts: Computational Practices, which is the development of skills in computational thinking concept, Computational Concepts which is to create understanding and habits of computational thinking, and Computational Dispositions which is the development of thinking.

The researcher has recognized the importance of computational thinking learning management. In the study titled "Kids Block Coding Game: A game to introduce programming to kids" (Forquesato, L. E. T. and Borin, J. F., 2018), it was found that "the sooner students begin to learn abstract theoretical concepts, the faster students can understand the content and learn more easily. and can be easily applied to the next level or applied at a higher level." Therefore, this research focuses on promoting the learning of computational thinking among elementary school students or young children between the ages of 6-12, which is the age when they begin to concentrate and do activities longer. Moreover, promoting the learning of computational thinking to elementary school students is an important starting point for students to have a foundation for systematic thinking and problem-solving. This will lead to further development in 21st-century skills (Geisinger, 2016) and desired career in the future.

In accordance with elementary school students, using concrete or tangible hardware while learning will have better results for students than learning via electronic device only. Thus, the researcher focuses on developing a toy in the combination of physical and virtual kits together.

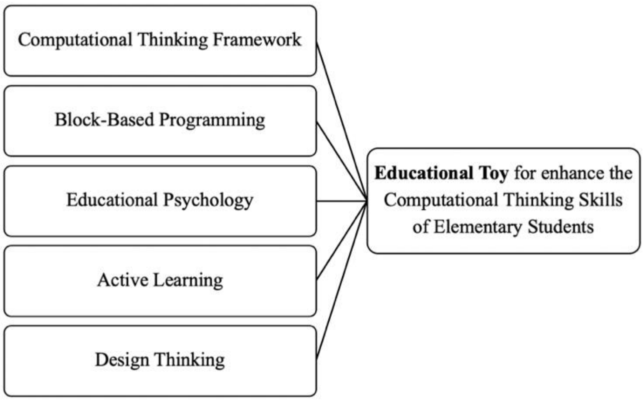
For this reason, the researcher intends to promote the learning of computational thinking among elementary school students by applying the hardware to improve computational thinking skills in the form of a robot pet. Because learning the principles of computational thinking at the elementary level will result in students having effective problem-solving skills and systematic thinking. This will also make it easier for students in the future to understand more difficult and complex theories or principles and will lead to the Sustainable Development Goals about Quality Education and Reducing Inequalities.

1.1 Objective

To develop block-based programming hardware in the form of a robotic pet that is suitable for effectively promoting the learning of computational thinking among elementary school students.

1.2 Research Framework

Figure 1: Research Framework



2. Literature Review

2.1 Computational Thinking Framework

(Grover & Pea, 2013) explains that the Computational Thinking Framework is the methods used to formulate issues and their answers, and how to represent such solutions in a way that an information-processing agent can use them to their fullest potential.

The computational Thinking Concept refers to the process of problem-solving and systematic thinking which based on the seven “big ideas” of computing. First of all, computer use is a form of human creativity. Secondly, information and detail are minimized in order to concentrate on ideas important for comprehending and resolving problems. Thirdly, data and information aid in the production of knowledge. Fourthly, algorithms are tools for formulating and developing computational problem-solving techniques. Fifthly, the creative process of programming results in computational artifacts. Sixthly, computational approaches to problem-solving are made possible and encouraged by digital devices, systems, and the networks that connect them. Finally, innovation in other sectors, such as science, social science, humanities, arts, medicine, engineering, and business, is made possible by computing.

2.2 Block-Based Programming

Block-based programming has several key features that differentiate it from other types of programming such as regular text. Block-based programming uses puzzle-like programming as a tool to provide visual signals to the user about how and where commands might be executed. Figure 2 shows a block-based program written in Scratch. Block-based programming is designed for children start with 5 years old, but most environments are designed for children 8 to 16 years old. Programming in a block-based environment uses a drag-and-drop programming style. For instance, if two commands cannot be combined to create a valid statement, then the program is prevented from merging. In this way, a block programming environment can prevent syntax errors while maintaining programming practices by collecting instructions one at a time. (Forquesato & Borin, 2018)

(Weintrop, 2019) states that block-based programming has writing features that support beginners like elementary school students. For example, block-based programming presents an existing set of instructions to users as of jigsaw boxes that are easy to browse in which users can drag commands to their program (Figure 2). Inside each jigsaw box is conceptually organized and color-coded. This allows users to browse through an existing set of commands to see what is possible. Instead of having to guess what to write. Meanwhile the drag-and-drop approach to composition greatly simplifies typing, and can also help reduce errors caused by spaces or misuse of symbols. As a result, block-based programming will be more accessible to students without worrying about typing problems. Another distinguishing feature of block-based programming is the graphical representation of each programming instruction, allowing natural language to be used to describe the behavior of the instructions. With the above features, block-based programming is the most popular form of programming to be used to teach those who have no programming background before.

Figure 2: Example of Block-Based Programming

Source: Weintrop, D., Shepherd, D. C., Francis, P., & Franklin, D. (2017). Blockly goes to work: Block-based programming for industrial robots. 2017 IEEE Blocks and Beyond Workshop (B&B)

2.3 Educational Psychology

Bruner's Theory of Intellectual Development divides the development of human intelligence into six characteristics: 1) the increased growth can be observed by increasing non-binding responses to specific natural stimuli that occur at the moment 2) event-dependent growth that occurs within the person that is consistent with the environment. 3) intellectual growth which involves increasing the ability to speak to oneself and others, and using words and symbols on what the person has done or what will be done. 4) cognitive growth depends on systematic interactions between Teachers and students 5) Teaching can be facilitated by linguistic materials which ended up being not only a medium for exchange. It is also a tool that students can use to direct themselves to the environment. 6) cognitive development is seen through an increase in the ability to deal with multiple events at the same time.

Piaget's Theory of Cognitive Development is a theory that studies the cognitive processes of children from birth to adolescence. This theory has greatly influenced the knowledge of developmental psychology. Especially in the part cognitive Piaget believed that the goal of human development is the ability to think rationally with abstraction the ability to make reasonable assumptions and the ability to formulate rules and solve problems. Piaget said humans have two basic innate tendencies: Organization, which is internal management by a method of combining processes in a continuous systematic system, and Adaptation, which means adapting to the environment, is a trend that is only born Human adaptation is caused by interaction with the environment. This adaptation consists of two processes, namely Assimilation and Accommodation. The result of the change will cause cognitive development from one stage to another until finally reach the stage called Operation, which refers to the ability of children to think back. This is considered the heart of Piaget's cognitive development.

2.4 Active Learning

Active learning is learning management that focuses on how students interact with teaching and learning within the classroom. Most importantly, it encourages students to develop advanced thinking processes (Higher-Order Thinking) by analyzing, synthesizing, and evaluating. Not only be good listeners, but students must read, write, ask questions, and have discussions together. In addition, students need to be put into practice concerning their knowledge and needs as the highest priority. This will change the role of the student from a recipient of knowledge to a participant in building knowledge within the classroom.

The importance of active learning consists of 4 important factors as follows (Prince, 2004):

1) Active learning promotes the independence of students' thoughts and actions, judgment, and creativity. Students will have the opportunity to participate in practicality and use discretion in thinking and making decisions, and find their learning style to become a thinker and self-determination. Therefore, active learning is a learning management approach that aims to enable students to develop higher-order thinking in critical thinking, analysis, problem-solving, assessment, decision-making, and creativity.

2) Active learning encourages effective cooperation among students, which co-operation in a good group performance of students will lead to overall success in the classroom.

3) Active learning encourages students to focus on their studies, motivates them to study, and makes students demonstrate competence. Students actively participate in activities in an environment supportive through the use of various activities provided by the teacher. Students can choose to learn various activities according to their interests and aptitudes, responsibility, and dedication to success.

4) Active learning promotes learning processes that lead to positive development for both students and teachers. This is considered a change in teaching and learning where students will have the opportunity to choose their aptitudes, interests, and abilities that are individual differences in line with the concept of Multiple Intelligence to express their identity and potential. As for the teacher's aspect, there must be aware to change their role and seek methods and various activities to help empower individual students. This will result in teachers developing teaching skills and having expertise in their roles and responsibilities, and also develop oneself, work development, and student development at the same time

2.5 Design Thinking

The design thinking process is the process of solving problems by taking into account the problems or needs of users as the center. It focuses on achieving practical results that are technically feasible that can be developed into a functional product or process. It is cost-effective for businesses and can be used for commercial purposes, as well as able to meet real needs and help solve problems for users. The design thinking process consists of 5 steps as follows (Razzouk & Shute, 2012):

1) Empathize is to understand the needs of the user and bring it as a starting point for the next step of development. This can be done through an interview, answering a questionnaire, taking a quiz or making an observation, etc.

2) Define is to take all the information obtained from the Empathize process to analyze and summarize key points such as how the user looks and behaves. Have a problem or need? Why is there such a thing or need? The selection of suitable problems will be designed in the next step.

3) Ideate is the collection of ideas and solutions to problems arising from definition without limitations. It should brainstorm ideas from a variety of perspectives and methods which focuses on the number of concepts as much as possible to be evaluated and summarized as the most suitable idea to solve such problems.

4) Prototype is the creation of prototypes to be tested with target users before actual production. The purpose is to test whether such methods are suitable for solving real user problems. For example, can it meet the needs? can it solve the problem for users? It also helps to reduce errors before they are manufactured and put into commercial use.

5) Test is an experiment that brings prototypes to be used in practice to test or experiment for users who are the target audience first. It focuses on performance testing, evaluation, and collecting feedback from real users to bring the data obtained from the test to improve before being tested again or put into practice.

2.6 Educational Technology Toys

In general, the computational toy consists of a programming part and a robot or fictional character known as a “sprite” which is controlled by programming. (Yu & Roque, 2019) have classified toys into three categories: physical kits,virtual kits and Hybrid kits with different characteristics as shown in Figure 3

1) A physical kit is a kit in which all components are physically accessible. The physical kit typically consists of real robot assembly for programming and supporting materials or accessories. Most physical kits consist of one robot with moving wheels. Some robot may be designed to resemble animals.

2) A virtual kit is a mobile or computer application which has no physical parts. Most virtual kits are in the form of games. The way to play is to enter commands to make the program perform certain tasks. Such applications often consist of virtual fictional characters called "sprites," game scenes, or stories and a block set for graphical programming.

3) A hybrid kit is a set consisting of both tangible parts and virtual parts which can be categorized into kits with real robots and graphical programming environments or sets with virtual sprites and tangible programming environments. Kits with real robots and graphical programming environments usually consist of real robots. The robots of the hybrid kit use wheels to move and often integrate sensors, devices, light, and sound into the robots to add fun to young users.

Figure 3: Difference of Computational Toys

The main design features of the three category kits: physical, virtual, and hybrid kits.

Kit categories	Major design features
Physical kits	• All components are tangible • Typically consist of a physical robot, a set of coding blocks, and some supporting materials • All robots move around using wheels • Some robots include sensors, lights, and sound devices • Most kits separate the coding blocks and the robot • The design of coding blocks primarily uses tangible tiles or cubes • Many kits provide supporting materials such as adventure maps, craft materials, storybooks, or coding cards to help scaffold children's play experience. • A few kits are based on board games or storybook • Puzzle piece is a common form for the coding block design • Different colors are utilized to make different-command blocks more distinguishable • Most programming commands involve motion
Virtual kits	• Mobile or PC-based applications • Most kits are in the form of video games that typically include game characters, game or story scenes, and a set of graphical coding blocks • Most video-game-based kits have rich scenes and different playing levels, more complex computational ideas will be involved as the game levels go up • A few kits are designed for children to create interactive stories and animations • Virtual kits generally include various coding blocks of operations • Puzzle piece and square are a common form for the coding block design • Different colors are utilized to make different-command blocks more distinguishable • Most programming commands involve motion

Hybrid kits	• Including both tangible parts and virtual parts
	• Kits with physical robots and graphical programming environments usually consist of a physical robot, a mobile-based coding application, and some supporting materials:
	    • The robots use wheels to move
	    • The robots usually include sensors, light and/or sound devices
	    • Graphical programming environments that ask children to create programs by dragging and dropping the blocks together
	    • Some kits provide some supporting materials, such as adventure maps and craft materials
	• Kits with virtual sprites and tangible programming environment generally consist of a virtual game or animation application and a set of tangible programming blocks:
	    • Ask children to create a sequence of code by connecting tangible blocks to control a virtual sprite
	    • The virtual game parts of these kits usually have rich scenes and different playing levels for children to explore
	• Puzzle piece is a common form for the coding block design
	• Different colors are utilized to make different-command blocks more distinguishable
	• Most programming commands involve motion

Source: Yu, J., & Roque, R. (2019). A review of computational toys and kits for young children. International Journal of Child-Computer Interaction, 21, 17-36. https://doi.org/https://doi.org/10.1016/j.ijcci.2019.04.001

3. Methods

In the development of educational toy for effectively promoting the learning of computational thinking among elementary school students by using the Design Thinking Process, the researcher has the steps as detailed as follows:

1) Empathizing by researching the literature review in the topics including computational thinking framework, block-based programming, educational technology toy concepts and creations, active learning for elementary students, and educational psychology.

2) Defining all the information obtained from the Empathize process to analyze and summarize the key points. and select appropriate issues to be designed in the next step.

3) Ideating the idea from the Defining process to meet the need.

4) Prototyping by design and developing educational toy for enhancing elementary students' Computational Thinking Skills.

5) Testing the prototype by doing the structure interview with the expert the get the feedback.

4. Findings

The findings of the development of educational toy for enhancing elementary students' Computational Thinking Skills are as follows:

4.1 Research and development (R&D)

Based on the literature review related to the development of educational toy that is suitable for promoting the learning of computational thinking principles for students in an efficient way can be concluded as follows:

1) Elements of the principles of Computational Thinking that focuses on development consists of 4 things as follows

1.1) Decomposition is the ability to break a problem into sub-problems or sub-problems. Organizing smaller problems can reduce the complexity of the problem, making it easier to solve.

1.2) Abstraction is about simplifying a problem or task by focusing on the essential parts. And it is about collecting all relevant information and deleting unnecessary details.

1.3) Pattern Recognition is the ability to recognize and use patterns to describe and represent sequences in data or processes. Looking at the pattern of the problem makes it possible to predict how things will work or what might happen in a given situation.

1.4) Algorithmic Thinking is thinking to find steps and ways to solve problems. An algorithm is an ordered, logical, and precise set of rules or instructions that are necessary to solve a problem or achieve an objective. The steps can be specified as commands such as verbal or written.

2) The block-based programming is programming in which the available instructions are presented to the user in the form of easily accessible puzzle boxes. Users can drag commands into their programs Inside each puzzle box are conceptually organized and color-coded. This allows the user to browse the existing set of commands to see what is possible. Instead of guessing what to write, meanwhile the drag-and-drop layout method greatly reduces typing complexity and can also reduce errors caused by spacing or misuse of symbols.

3) Human cognitive development in Piaget's theory that corresponds to elementary school students, namely Stage 2, Concrete Thinking Operations, which ranges in age from 2 to 11 years, divided into 3 parts as follows:

3.1) Preconceptual Phase Age 2 – 4 years is when the child begins to have the ability to use language. and understand the meaning of the symbols around them that relate only to themselves.

3.2) Intuitive Phase Age 4 – 7 years Children have intellectual development and thinking but are unable to use real reasoning. Decisions are largely based on perception.

3.3) Concrete Operations 7-11 years old Children at this age can create rules and regulations. and set criteria in Classifying things into categories Children begin to have the ability to think backwards. and have an understanding of Reason and able to comprehend things perfectly.

4) Active learning is learning management that focuses on having students interact with teaching and learning within the class. Most importantly, it encourages students to develop advanced thinking processes (Higher-Order Thinking) with analysis synthesize and evaluate.

5) Design Thinking consists of 5 steps: empathize, define, ideate, prototype and test.

By combining all findings together, it resulted in the types of intelligent toys and robots for children that are suitable for promoting the learning of computational thinking for elementary school students are hybrid kits, which are sets that include both tangible parts and virtual parts. The tangible part is a real robot and the virtual programming part is made up of electronic devices such as laptops or tablets.

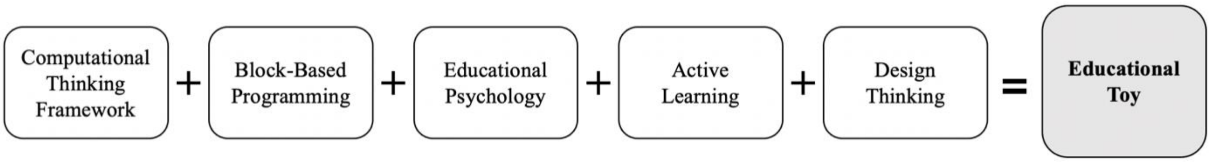
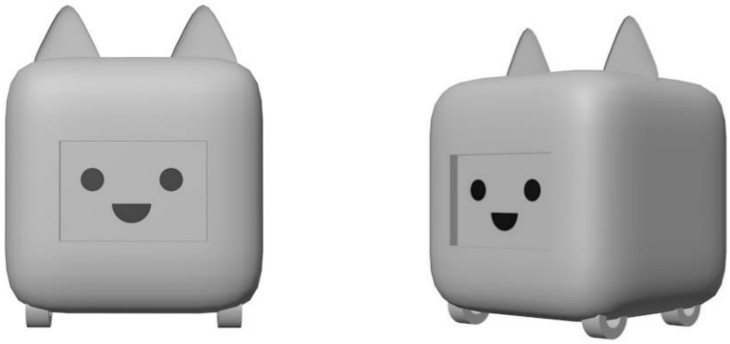


Figure 4: Findings Summary

4.2 Prototype Development

1) The first draft of an educational toy for enhancing elementary students' Computational Thinking Skills created with Cinema4D program, which has only an external (interface) appearance that cannot be 3D Printing. It's the draft for designing the concept.

Figure 5: First Draft

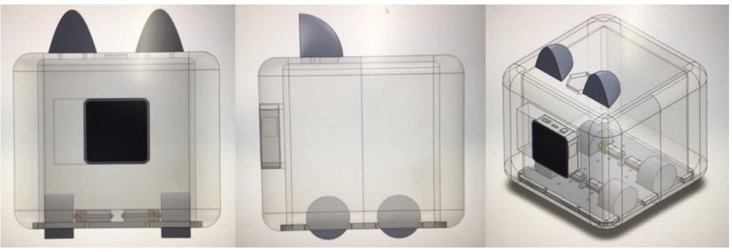


2) The mockup of an educational toy for enhancing elementary students' Computational Thinking Skills. It is a mockup for determining the size and positioning of the microcontroller, the wheels, and other hardware. The size which does not include the ear is 15 centimeters in width, 15 centimeters in length, and 15 centimeters in height.

Figure 6: Mockup

3) The second draft educational toy for enhancing elementary students' Computational Thinking Skills is created with the SOLIDWORKS program which is a ready-to-print design special for 3D printing with a layout for inserting internal components such as the microcontroller and the wheels.

Figure 7: Second Draft



4) The complete prototype of an educational toy for enhancing elementary students' Computational Thinking Skills included an external structure that resembles a pet from 3D printing and the internal structure and hardware.

Figure 8: Completed Prototype

4.3 Interview the Experts

Researcher conducted structured interviews with expert for a usability evaluation of hardware prototypes to certify an educational toy for enhancing elementary students' Computational Thinking Skills. The interview questions are as follows:

> Question 1) What do you think about the performance of the evaluative pet robot programming hardware?"
>
> Question 2) Do you think that the educational toy for enhancing elementary students' Computational Thinking Skills has all the effective components and functions in use?
>
> Question 3) Do you think that the appearance of the hardware which is designed to resemble a pet is suitable for use with elementary school students?
>
> Question 4) Do you think that this educational toy is suitable for use with elementary school students?
>
> Question 5) Do you think that this educational toy is suitable to use as an instructional tool that can promote learning computational thinking?

In accordance with the interviews, it can be summarized to these following details.

1) Hardware performance is good. It's high efficiency and also uses the equipment that can be easily procured. So, the hardware is effective enough to be used in the class.

2) The functions of the hardware aligned with the STEM (Science, technology, engineering, and mathematics) education. The hardware can be use from basic to advanced levels which means every level of elementary students can use the hardware easily.

3) The hardware was designed to attract students by having a pet-like form encourage students to focus more, have an active learning and participation in class.

4) The educational toy is very suitable for teaching in elementary school because it helps students understand the concept and understand how to apply the computational thinking better.

5) The developed educational toy can enhance student's computational thinking skills by let student's do the activities with the toy. For example, calculate the movement of the robot, calculate the illumination distance of the light, and calculate the display of various graphics on the robot screen. All of these things require logic and all calculations are applied.

After researcher received the feedback, it can be summarized as follow:

The educational toy can improve the computational thinking skills by using it together with the activities that let students use the problem-solving skills. For example, student need to control the educational toy to avoid some obstacles and go to the finish point. By playing this activity, it will make children practice using computational thinking skills and also make them feel used to programming with electronic device. This also encourage the active learning in the class more which is very beneficial for elementary students in learnings.

Figure 9: The example of activity that used the prototype as a teaching material

5. Conclusion

To develop the suitable educational toy for enhancing elementary school students' computational thinking skills, researcher focusing on enhancing 4 core of Computational thinking skills of elementary students which are decomposition, abstraction, pattern recognition and algorithmic thinking. In order to create the hardware that user friendly for kids, researcher selected the perfect age range of kids to start learning computational thinking skills and used block-based programming platform as a simply commanding channel for students together with developing active learning activities that use educational toys in class.

The conclusion of the development of educational toy for enhancing elementary students' Computational Thinking Skills are as follows:

Prototype of educational toy for enhancing elementary students' Computational Thinking Skills is designed to look like cat and printed with 3D Printing and the internal structure consists of the following main parts which are 1) Microcontroller 2) Wheels for movement 3) Motors for controlling the speed 4) Battery and 5) Hexagon shaped LED Light.

As the feedback from expert, this educational toy have a good hardware performance, align with STEM course, appealing cat-like interface design, eligible for elementary student and Suitable for enhancing Computational Thinking Skills.

The prototype can connect to a block-based programming platform to control and input commands in the form of a block. The prototype can be connected to the block-based programming platform through the API key. The prototype will act by following the commands running from the command in the block-based programming platform.

6. Suggestion

To use the educational toy for enhancing elementary students' Computational Thinking Skills in the classroom, the teacher should introduce the objective of the lesson first and also summarize it again by the end of the class to make children remember to concept and practice to skill.

In the further research, researcher should implement the computational thinking toy in the elementary class and conduct experimental research regarding Computational Thinking skills improvement.

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