Computational Thinking and STEM Education

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Content

- Computational Thinking (CT)
- Three ways of developing CT
  - CT & Mobile Computing
  - CT & Programmable Robotics
  - CT & Modeling/ Simulation
- Role of CT in STEM Education
- Curriculum Design for CT Development in STEM Education

CT Framework

Computational Thinking

Computational Thinking Knowledge Fundamental programming knowledge	**Knowledge in programming language context** 1. Sequence 2. Events 3. Repetition 4. Conditional 5. Parallelism 6. Naming (Variables) 7. Operators 8. Manipulation of data and elementary data structure	**Outcome of programming experiences with fundamental programming knowledge** 1. Programming fundamentals, such as sequencing, branching and looping, and interacting among objects 2. Algorithms in programming, such as sorting and searching
Computational Thinking Practices Process and outcomes of practices for logical thinking and problem solving skills development	**Processes of practices** 1. Recognize computational problems, find workable means 2. Understand the order of precedence in solving the problem 3. Decomposing tasks into subtasks 4. Gather & arrange relevant information for problem solving 5. Use the programming environment /language to code accurately and with clear documentation 6. Recognize logical sequence, branching & looping relationships 7. Put the program for testing & debugging	**Outcomes of practices with skills for logical thinking and problem solving development** 1. Reusing and remixing (building on other's work) 2. Being incremental and iterative (a) Iterative, recursive, and parallel thinking 3. Abstracting and modularizing (a) Abstraction and pattern generalization (b) Structured problem decomposition 4. Testing and debugging 5. Algorithmic thinking (a) Systematic processing of information (b) Symbol systems and representations (c) Algorithmic notions of flow of control (d) Conditional logic
Computational Thinking Perspectives Evolving understandings of themselves, their relationships to others, and the technological world around them	**Experiences in coding** 1. Expressing 2. Questioning 3. Connecting	**Outcomes of experiences with following key perspectives** 1. Personal interests in coding 2. Willingness to engage further in coding 3. Positive perception of coding 4. Confidence in coding 5. Computational identity 6. Digital empowerment

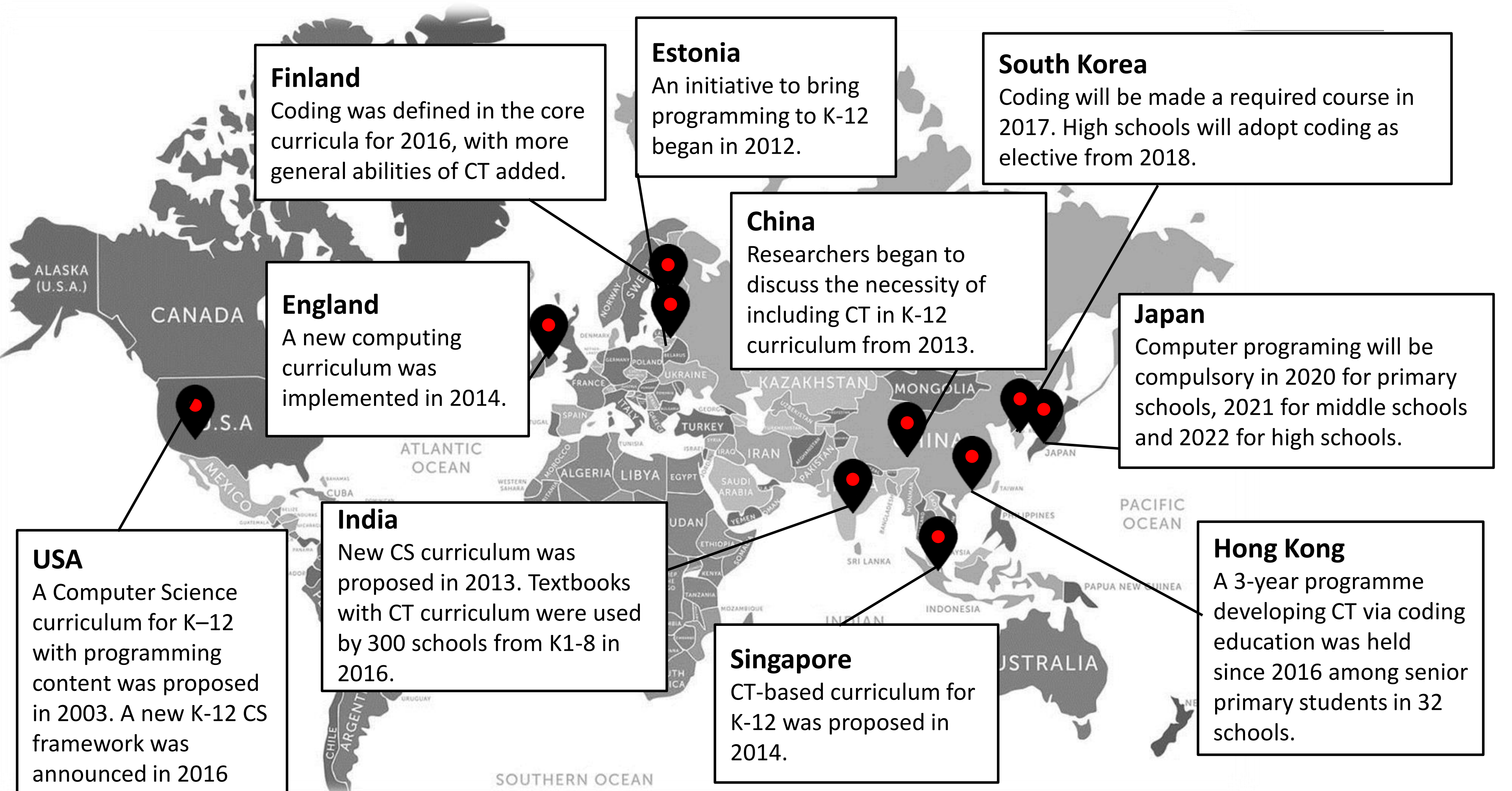
Constructionism as the Learning Theory Underlying CT Development

- Constructionism refers to the cognitive development and learning involved in building knowledge structures through interacting with natural and designed environment (Papert, 1991)

- Students take part in construction of knowledge by building a meaningful product (e.g., a program) for others or themselves (Kafai & Resnick, 1996; Lye & Koh, 2014)

- Constructionism emphasizes hands-on practice for conceptual development and learning by making

Examples of CT Development



Finland
Coding was defined in the core curricula for 2016, with more general abilities of CT added.

Estonia
An initiative to bring programming to K-12 began in 2012.

South Korea
Coding will be made a required course in 2017. High schools will adopt coding as elective from 2018.

England
A new computing curriculum was implemented in 2014.

China
Researchers began to discuss the necessity of including CT in K-12 curriculum from 2013.

Japan
Computer programing will be compulsory in 2020 for primary schools, 2021 for middle schools and 2022 for high schools.

USA
A Computer Science curriculum for K–12 with programming content was proposed in 2003. A new K-12 CS framework was announced in 2016

India
New CS curriculum was proposed in 2013. Textbooks with CT curriculum were used by 300 schools from K1-8 in 2016.

Singapore
CT-based curriculum for K-12 was proposed in 2014.

Hong Kong
A 3-year programme developing CT via coding education was held since 2016 among senior primary students in 32 schools.

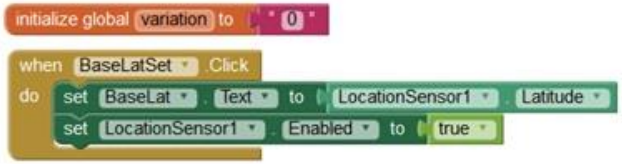
CT and STEM Education

3 possible ways of developing CT

- CT Skills & mobile computing
- CT Skills & programmable robotics
- CT Skills & simulation

CT Development through Coding

- CT is originally based on Seymour Papert's work (1980) referring to the expression of powerful ideas through computational representations (Papert, 1996)
- It is the thought processes involved in formulating a problem and expressing its solution(s) so that a computer- human or machine can implement (Wing, 2014)
- It involves designing systems, understanding human behavior and solving problems by applying the concepts fundamental to computer science (Wing, 2006)
- Coding is an effective means for developing computational thinking
- Block-based programming environments (e.g., Scratch, App Inventor) allow even young learners to learn how to code or write programs

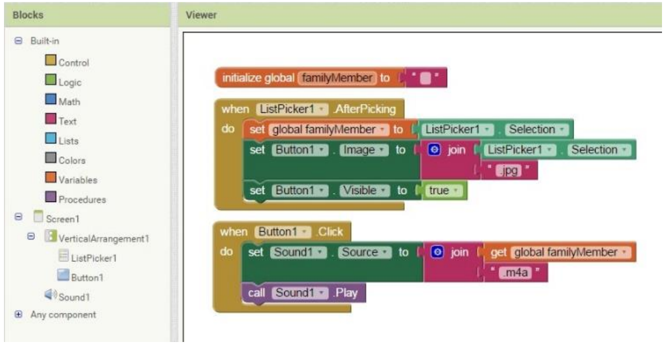


CT & Mobile computing

- Examples of platform: App Inventor, Swift playground
- Students to develop mobile apps by means of coding

1. Input: collect data (detect events) from:
   - sensors of mobile devices (eg. Accelerometer sensor, location sensor)
   - user input (eg. Submitting answers, pressing certain keys)

2. Process: automated computation
   based on learners' programs and data collected



3. Output: application to respond to the input

CT & Mobile Computing

- A framework of CT (Brennan & Resnick, 2012):

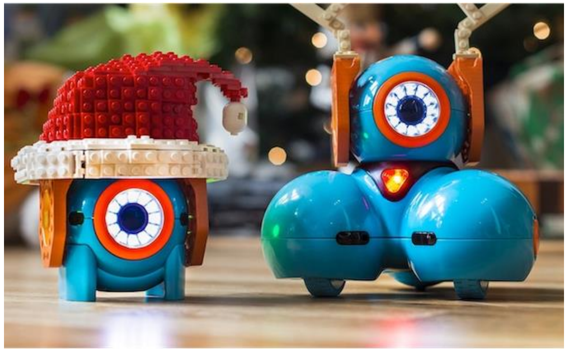
CT concepts	CT practices	CT perspectives
Sequences	Being incremental & iterative	Expressing
Events	Testing & debugging	Connecting
Loops	Reusing & remixing	Questioning
Parallelism	Abstracting & modularizing	
Conditionals		
Operators		
Data		

CT & Programmable Robotics

- Examples : Lego Mindstorms, mBot, iRobot, Botball, FIRST, Dash & Dot

- Students to build a robot with sensors and interact with it with coding

1. Input: collect data from:
   - different environmental sensors (eg. temperature, ultra-sonic, rotation sensors);
   - input modules (eg. switches, buttons)



2. Process: automated computation based on learners' programs and data gathered from smart mainboard (eg. arduino) via wireless connection (eg. bluetooth/ wifi)

3. Output: robot reacts accordingly via output modules (eg. motor, wheels, buzzers)

CT & Programmable Robotics

A learning progression in educational robotics (Sullivan & Heffernan, 2016):

Sequencing
- Ability to put items into specific order
- Foundation of programming

⇨

Causal Inference
- Based on comparison between the expected movement and immediate feedback from the programmed object
- Set up hypothesis on why the expected movement was not observed

⇨

Conditional Reasoning
- Ability to abstract a rule for the behavior
- Use of environmental sensors to work with robotic devices
- Eg. sensory-reason-action-loop

⇨

Systems Thinking
- Understanding of interacting functions of related parts of robotics device
- Interaction between microcomputer, actuators (eg. motor, bulbs) & sensors

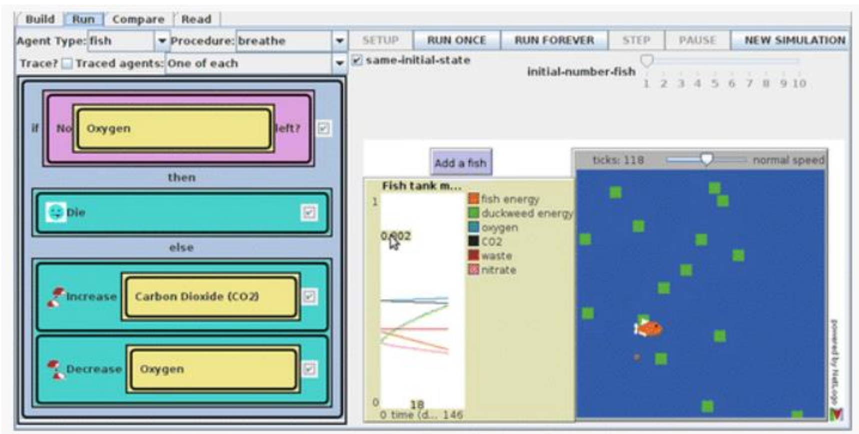
CT & Modeling/Simulation

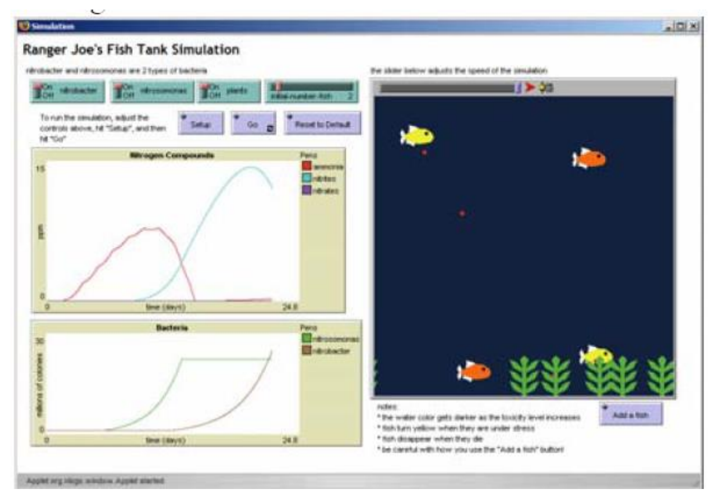
- Example of platform: NetLogo

- Example: Modeling the ecosystem of food chain & waste cycle

(Sengupta, 2011; Tan & Biswas, 2007)

  - Learning task: being able to sustain a number of fish over a period of time





CT & Modeling/Simulation

1. Input: parameters and commands set by learners

2. Process: rule-based simulation of natural phenomenon based on input parameters

3. Output: generation of behaviors that support or contradict learners' hypothesis

CT Skills & Modeling/ Simulation

Categories of CT practices in STEM (Weintrop et al., 2016):

Data Practices
Collecting Data
Creating Data
Manipulating Data
Analyzing Data
Visualizing Data

Modeling & Simulation Practices
Using CT models to understand a concept
Constructing CT models
Assessing CT models
Designing CT models
Using CT models to find and test solutions

Computational Problem Solving Practices
Preparing problems for CT solutions
Programming
Choosing effective CT tools
Developing monocular CT solutions
Assessing different approaches/ solutions to a problem
Creating CT abstractions
Troubleshooting and debugging

Systems Thinking Practices
Integrating a complex system as a whole
Understanding the relationships within a system
Thinking in levels
Communicating information about a system
Defining systems and managing complexity

CT Skills & Modeling/ Simulation

Data Practices (Weintrop et al., 2016):

Data Practices	**Descriptions**	**Egs**
Collecting Data	• Propose systemic data collection protocols • Articulate how the protocols can be automated with CT tools	• Decide on what and how the data should be collected • Propose to collect rainfall on a daily/ weekly/ annual basis
Creating Data	• Define CT procedures • Run simulations	• Set/ add conditions for the simulation, eg. if no. of wolf>0 and no. of sheep =0, wolf will die
Manipulating Data	• Sorting, filtering, cleaning, normalizing, joining separate datasets • Manipulate datasets with CT tools • Reshaping dataset to be a more useful configuration for further investigation	• Sort data from ascending order • Find out the highest/ lowest rainfall and present separately for easier referencing
Analyzing Data	• Look for patterns and anomalies • Define rules to categorize data • Identifying trends and correlations	• Generalize rules from data
Visualizing Data	• Use conventional visualizations or interactive displays to present data	• Graphs and charts

Comparing the 3 ways of developing CT

	Mobile computing / app or game design	Programmable/ educational robotics	Modeling/ simulation
Platform/ example	App Inventor, Alice, iGame, Scratch, Logo, Game Maker	Lego Mindstorms, mBot, iRobot, Botball, FIRST	NetLogo
Renowned Framework	CT framework (Brennan & Resnick, 2012)	Computational learning progression in robotics (Sullivan & Heffernan, 2016)	CTSiM framework (Sengupta et al., 2016a)
Role of learner	As a designer: - Build one's own app As an inventor: - Create something new which can benefit the society	As a maker/ designer: - Build and program a robot As an inventor: - Create something new which can benefit the society	As a user/ designer: - Manipulate parameters on the platform
Role of teacher	As a facilitator: - Equip learners with skills in mobile computing - Provide sample app as scaffold of learning - Provide technical support	As a facilitator: - Equip learners with skills in robotics - Create challenges/ setting conditions for learners - Provide technical support	As a facilitator: - Model the use of platform - Guide students through the process of scientific inquiry

Role of CT in STEM Education

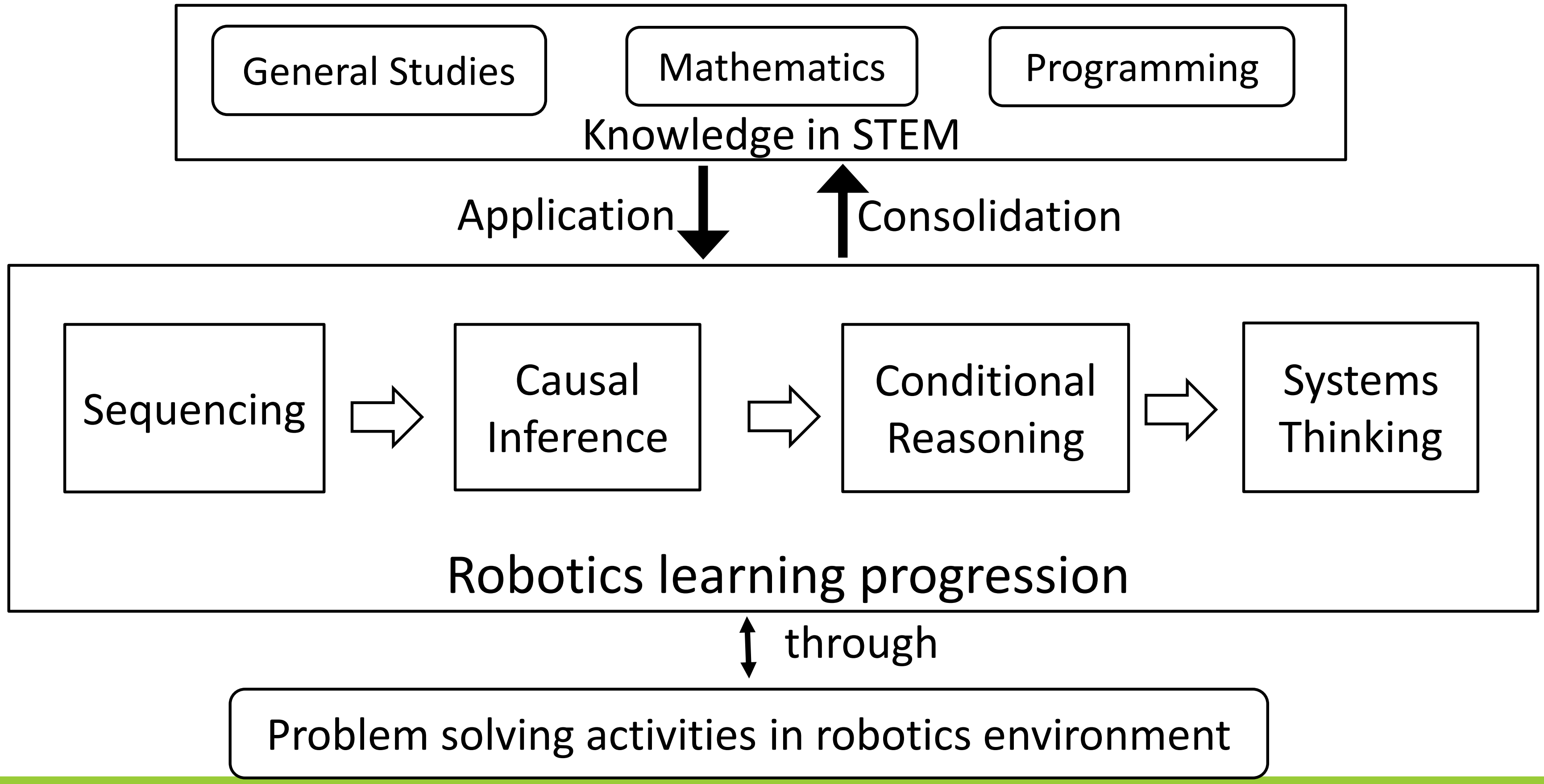
- CT skills help to deepen the understanding of STEM content areas for students (Guzdial, 1994; National Research Council, 2011; Repenning et al., 2010; Sengupta et al., 2013; Wilensky & Reisman, 2006)

- CT skills development help students to reflect productively on STEM activities which in turn help to cultivate problem solving and logical thinking ability of students:
  - E.g., when controlling a robot to run a maze, students engage in a problem-solving process, which requires skills such as decomposing a problem into sub-problems, and testing and debugging.

- Programming and computational modeling are effective vehicles for learning STEM concepts, e.g., friction, environmental conservation (Guzdial, 1995; Sherin, 2001; Hambrusch et al., 2009)

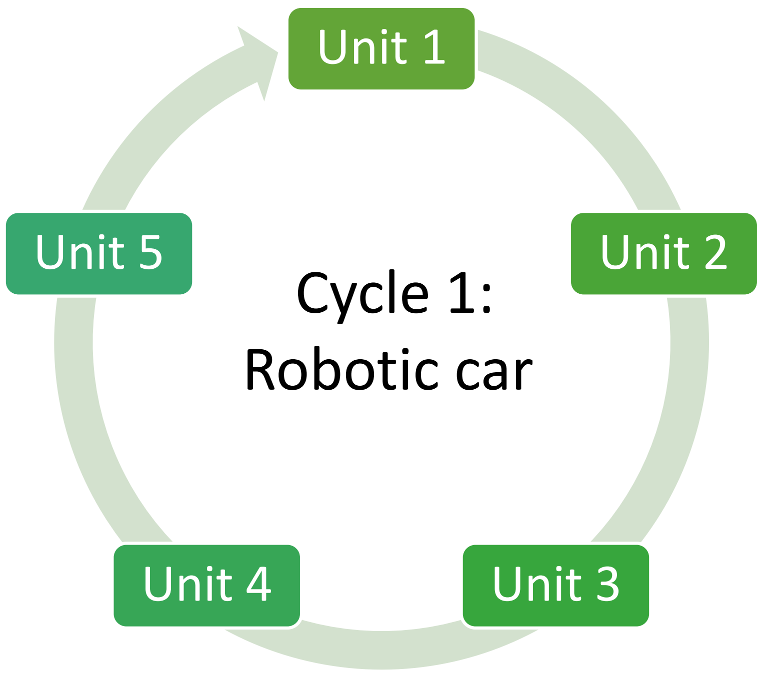
Curriculum Design for CT Development in STEM Education

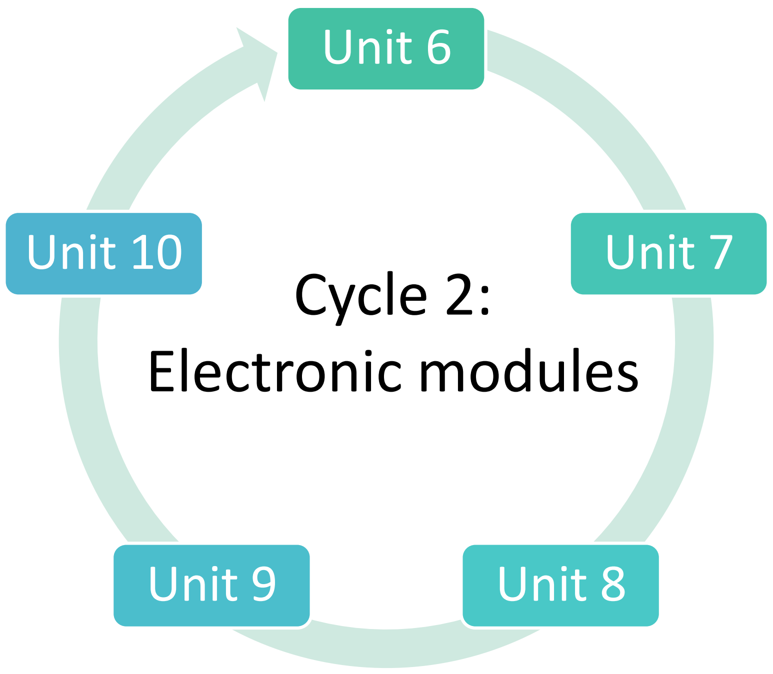
Based on a Conceptual Framework modified from Sullivan & Heffernan (2016):



Curriculum Design for STEM Education

- 2 cycles of robotics learning progression:





Curriculum Design for STEM Education

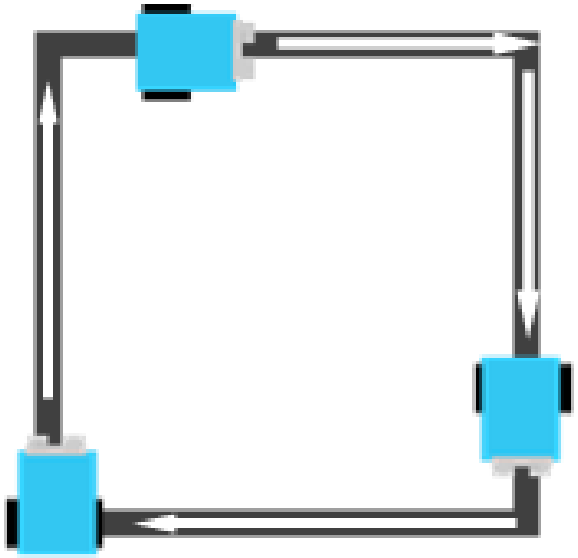
Modified from Brennan & Resnick (2012); Sullivan & Heffernan (2016):

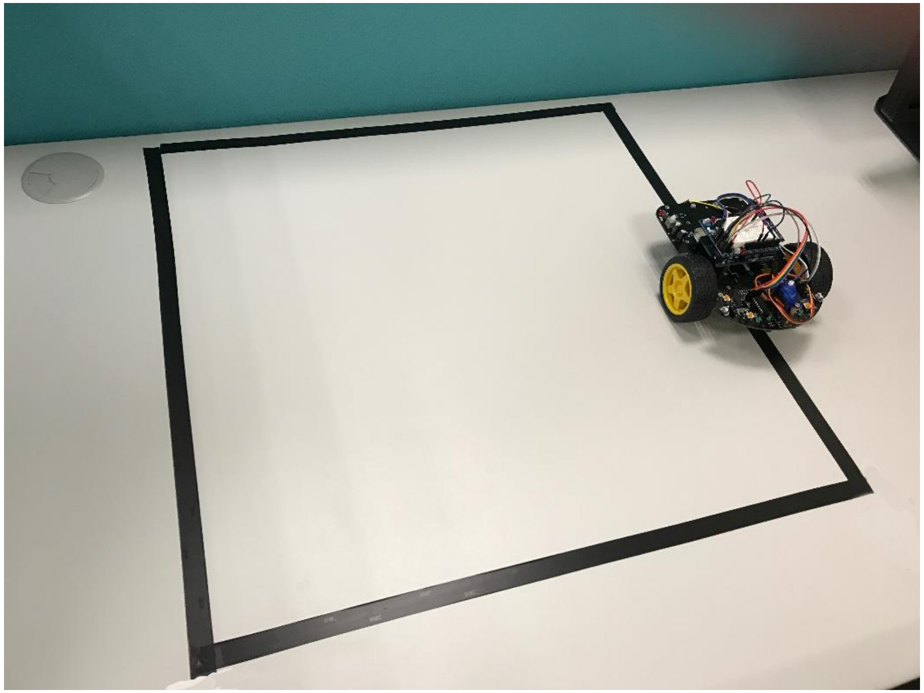
Course Design based on CT Progression in Robotics Learning				
CT knowledge	Sequences, Repetition, Naming (Variable)	Conditional, Operators	Manipulation of data and elementary data structure, Events	
	Cycle 1: unit 1 Cycle 2: unit 6	Cycle 1: unit 2-3 Cycle 2: unit 7	Cycle 1: unit 4-5 Cycle 2: unit 8-10	
CT practices		Testing & debugging, Being incremental & iterative, Reusing and remixing	Algorithmic thinking	Abstracting & modularizing
		Cycle 1: unit 1 Cycle 2: unit 6	Cycle 1: unit 2 Cycle 2: unit 7-8	Cycle 1: 3-5 Cycle 2: 9-10
Robotics Learning Progression	Sequencing	Causal inference	Conditional reasoning	Systems thinking
	Cycle 1: unit 1 Cycle 2: unit 6	Cycle 1: unit 1-2 Cycle 2: unit 6	Cycle 1: unit 3 Cycle 2: unit 7	Cycle 1: unit 4-5 Cycle 2: unit 8-10
progression of learning				

Sample Task 1: My Autopilot Car

<u>Auto-piloting the robot moving along a square</u>

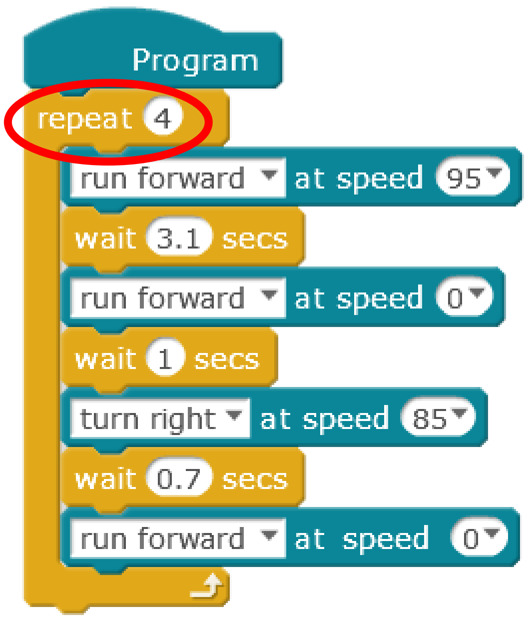
Requirement: develop a program to make the robot walk through a square.





Sample Task 1: My Autopilot Car

Possible solutions:



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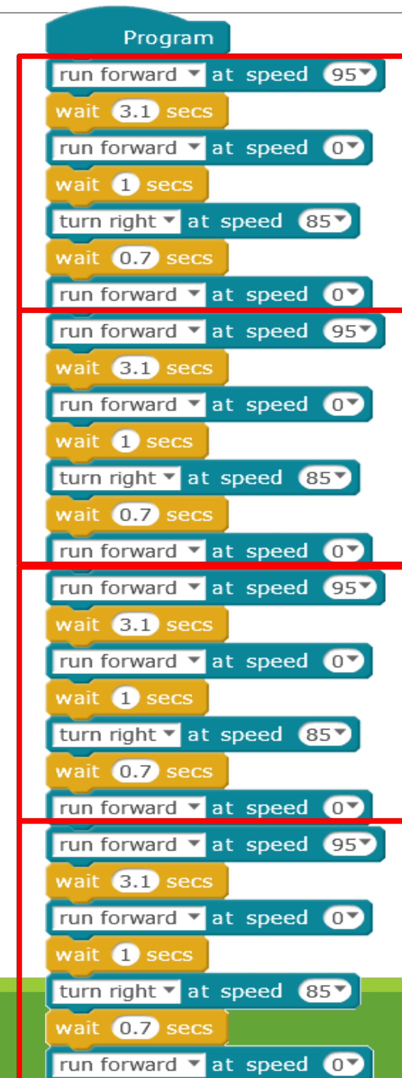


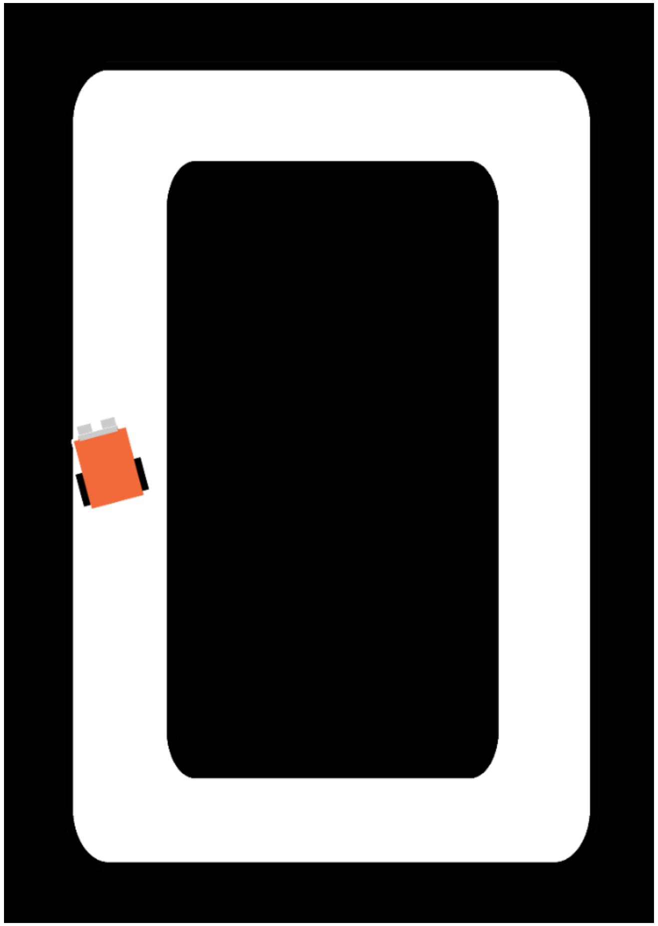
Sample Task 1: My Autopilot Car

Knowledge and skills involved:

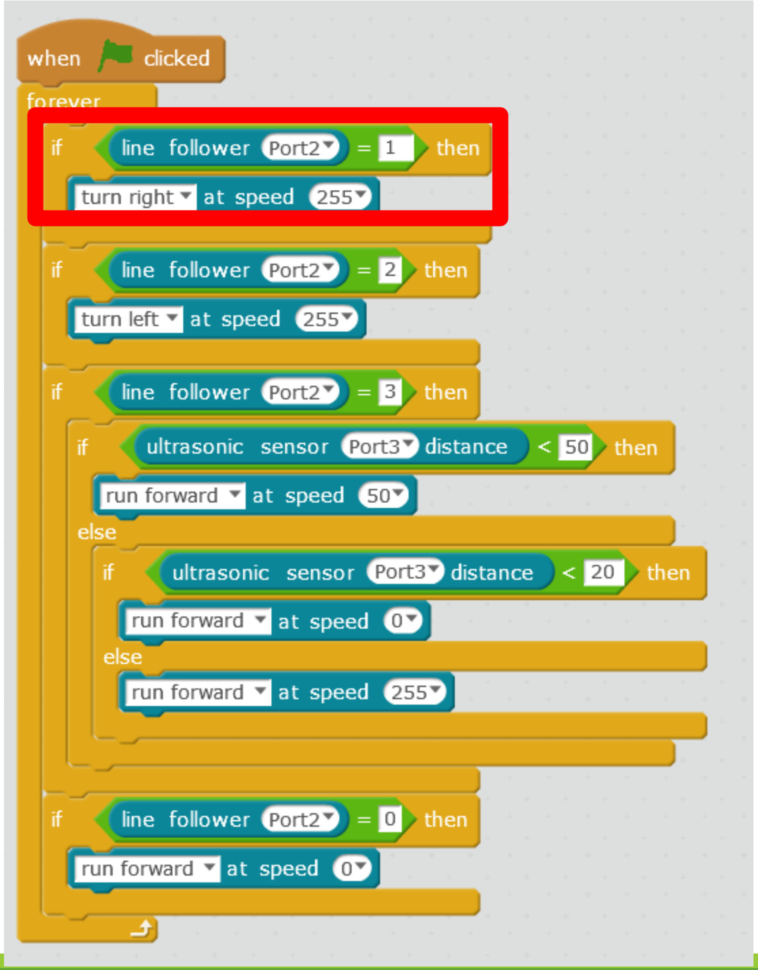
Course Design based on CT Progression in Robotics Learning	
CT Knowledge	Sequences, Repetition, Naming (Variable)
CT Practices	Testing & debugging, Being incremental & iterative, Reusing & remixing
Robotics Learning Progression	Sequencing
STEM areas	S: Manipulate & operate electronic toys domain as in general studies T: programming using scratch E: iterative modification of the program design M: measurement of speed and distance; use table to record statistics

Sample Task 2: Car Race

Requirement: develop a program to make the car run on the track. It will also slow down automatically when there is another car in front of it.

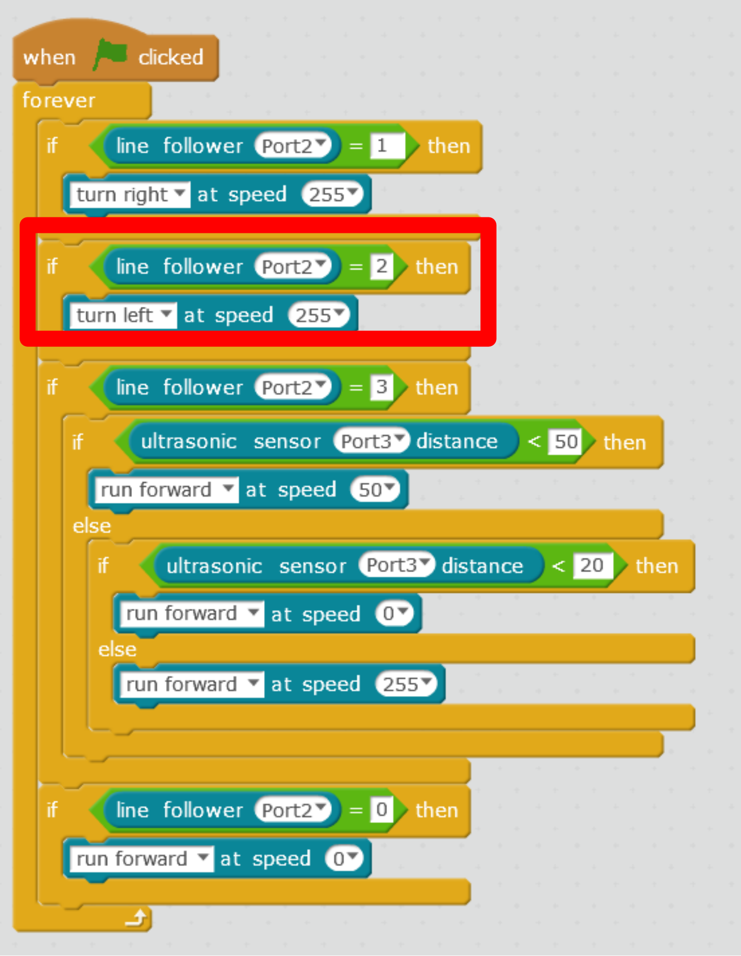


Sample Task 2: Car Race



- If the returned value is 1 (black color is detected on the left hand side)
  - it will turn right

Sample Task 2: Car Race

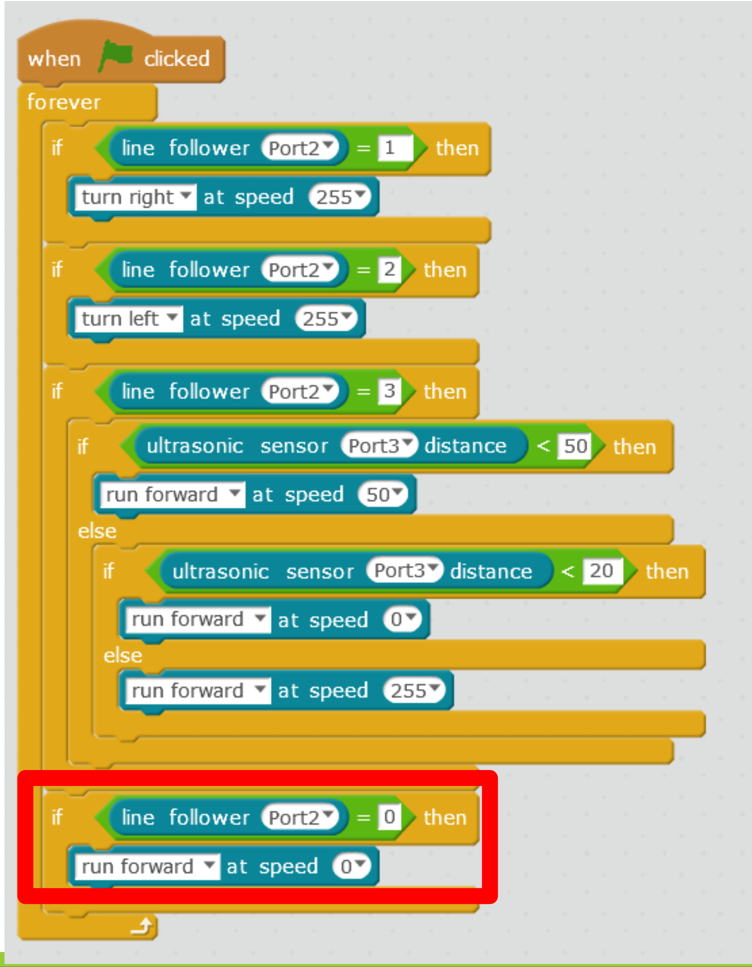


- If the returned value is 2 (black color is detected on the right hand side)
  - it will turn left

Sample Task 2: Car Race

- If the returned value is 3 (only white color is detected)
  - it will keep moving forward
- If there is another car in front of it
  - it will slow down
  - it will stop when too close

Sample Task 2: Car Race

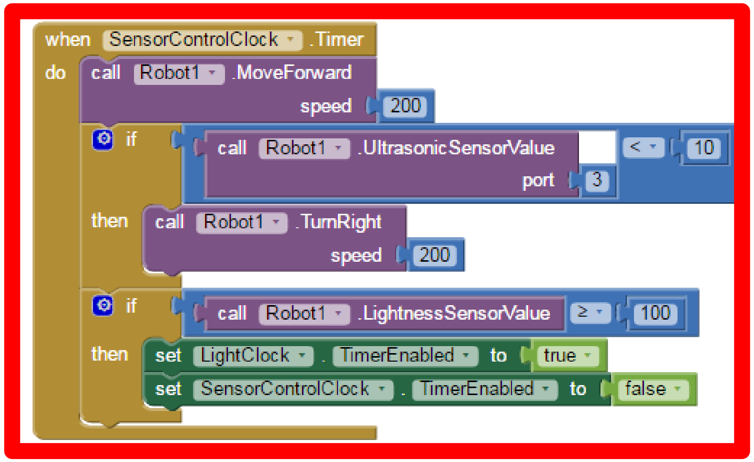


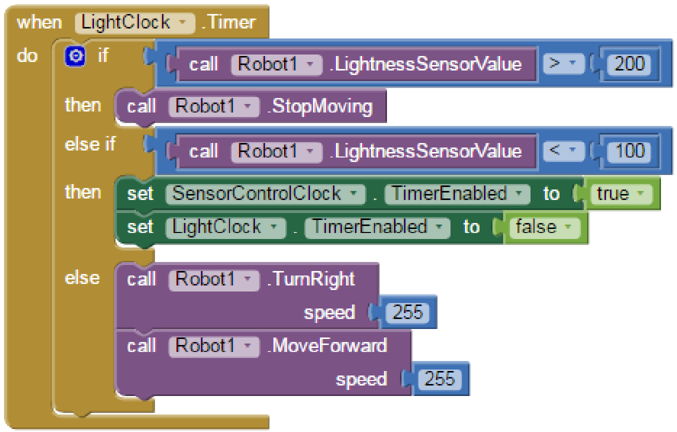
- If returned value is 0 (only black color is detected)
  - it will stop

Sample Task 3: Searching for light

Requirement: develop a program to make the robot avoid obstacles in a dark environment. It will circle around when the light is detected and will stop when the light intensity is high enough.

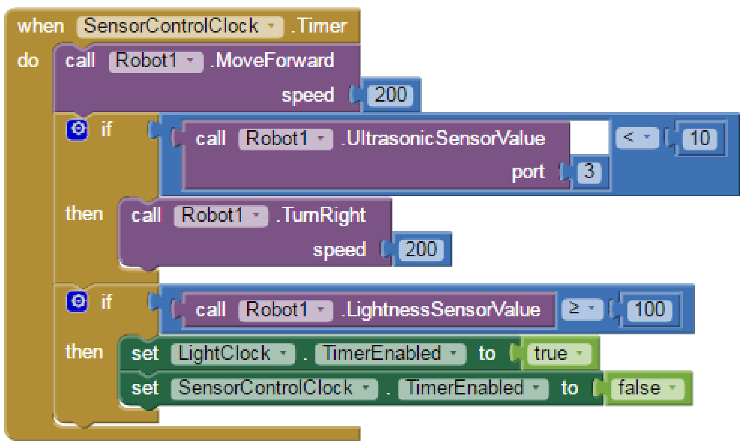
Sample Task 3: Searching for light

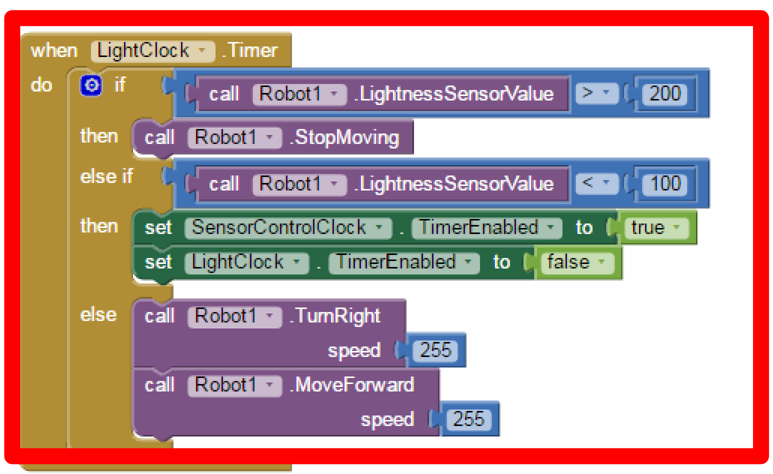




- the light intensity value is lower than 100
  - the code inside SensorControlClock will be executed
  - avoid obstacles which are 10 cm ahead

Sample Task 3: Searching for light





- Light intensity is higher than 100
  - code inside LightClock will be executed
  - robot will stop when the light intensity value is higher than 200
- Light intensity between 100 to 200
  - Robot circling around.
- Light intensity is lower than 100
  - LightClock will be disabled
  - SensorControlClock will be enabled
  - the robot will focus on avoiding obstacles again

To install a light bulb…

Conclusion: What is the Core of CT?

- Wing's definition of CT (2006): It involves "the thought processes involved in formulating problems and their solutions".

1. **Problem formulation**
   - The ability to discover problems in the real life or raise questions in the digital world
2. **Problem solving**
   - The ability to systematically process information and design the algorithm to solve problems

Conclusion: How Can We Develop CT?

Develop CT skills in order to facilitate problem formulation and problem solving

↓

Accumulate experiences in programming mobile apps/ STEM/ simulation on testing scientific hypothesis

↓

Consolidate these precious experiences as a thinking skill without delving deep into the technical knowledge

↓

Integrate the CT skills into one's expertise

Conclusion

- STEM education emphasizes the integration of Science, Technology, Engineering, and Mathematics into a cohesive learning paradigm based on real-world applications;
- CT plays a significant role in STEM education;
- Students can build digital physical devices with sensors, and use coding to control them to react with input data from sensors;
- In completing tasks such as controlling digital physical devices to run a maze, students engage in a problem-solving process through coding, which requires skills such as decomposing a problem into sub-problems, and testing and debugging;
- Both CT and STEM education stress learning by making. Students are required to build and create artifacts in these contexts, which is in line with the constructionist view of learning and teaching.

Computational Thinking and STEM Education

Thank You !

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