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Learning Computational Thinking Practices Through Agent-Based Modeling in an Informal Setting

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Abstract: In this qualitative study, I investigated the form of interaction when learners co-constructed computational thinking practices in an informal setting. This study focuses on the roles of five youth, three adult mentors, and a facilitator during a summer camp and documents how learners interacted to exchange ideas, collaborate, and accommodate other perspectives. Participants used questions that promote deep thinking to engage in computational thinking practices during the interactions. Analysis of data shows that learners developed computational thinking practices including interpreting, modeling connections to the real-world, manipulating parameters, discovering ideas to explore models, prompting, conjecturing, and making predictions when working on agent-based modeling and writing codes in NetLogo. These practices are further grouped together as model interpretation and connection to the real world, parameter manipulation and discovery, prompting and exploring, and making predictions/conjectures and generalizing. This study also finds some community-based practices such as practical wisdom, trying something and adjusting, and the use of network of resources relevant during interaction to develop computational thinking practices.

Keywords: *Agent-Based Modeling; Computational Thinking; Informal Education; Modeling.*

Introduction

Incorporating computer science (CS) in K-12 education has been gaining momentum among educators worldwide in recent years. This movement includes many nations in Europe (Angeli et al., 2016), the United States (Weintrop et al., 2016) and other parts of the world. In particular, mathematics and computer science educators (e.g., Lockwood, 2019; Weintrop et al., 2016) have identified computational thinking as a key mechanism for promoting CS education in K-12 settings (Yadav et al., 2018; Mouza, Yadav, & Ottenbreit-Leftwish, 2021). Computational thinking is a problem-solving toolset that goes beyond information technology fluency to applying computing principles such as abstraction, decomposition, generalization, pattern recognition, algorithmic and parallel thinking (Selby, 2015). The inclusion of computational thinking practices in science and mathematics has been widely received among different policymakers (e.g., CCSM, 2010; NRC, 2010; & NGSS, 2013), researchers (e.g., Wing, 2006; Lockwood, 2019, Yadav et al., 2017), technological organizations (e.g., Google, 2010), and individuals (e.g., Wolfram) among others. For instance, the authors of NGSS (2013) emphasized the growing importance of computation and digital technologies across the science disciplines and suggested that science's teaching and learning requires authentic investigation. They grouped authentic investigation into eight different practices, some of which emphasized computational thinking. Similar educational outcomes were suggested by the common core guidelines (2010), which encourages students to use technological tools to explore and deepen their understanding of concepts. A good way to access the affordability of technological tools in solving problems is when students work together (Jari et al., 2004).

In addition, researchers have identified collaborative learning as a means to optimize students' learning

(Johnson and Johnson, 1999). This study reports computational thinking practices that learners developed when working collaboratively on modeling tasks and coding in NetLogo. The study considers social interaction between learners, facilitators, and computational tools to describe how learners construct computational thinking practices while using NetLogo in an informal setting to explore an agent-based model that simulates disease spread and coding in such programming environment. In sum, this study provides insights into how learners construct computational thinking practices through agent-based modeling in an informal setting.

A practical way to explore mathematics and scientific concepts is through modeling, an aspect of mathematical or scientific exploration that presents occasions whereby learners can use mathematics or scientific knowledge to investigate their world. During modeling explorations, learners can use computational tools in various ways (such as interpreting, analyzing, evaluate) to carry out different stages of the modeling process (Bliss, Galluzo, Kavanagh, & Levy, 2018), which in turn, supports the development of computational thinking practices.

Modeling is a branch of mathematical or scientific learning that bridges the gaps between disciplinary concepts and the practical world. Mathematicians, scientists, and researchers now use agent-based modeling to investigate situations that may be difficult to explore in real life through computer simulations. An agent-based model (ABM) is a computational model for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) to understand a system's behavior and what governs its outcomes (Nicholls et al., 2017). This study considered the agent-based modeling situation in that it provided learners with the opportunities to model events that happened in their communities or at least have heard about. While investigating the world through ABM, users can develop and use a thought process known as computational thinking which was defined as a problem-solving toolset (Selby, 2015). These toolsets are becoming essential practices that create learning opportunities for learners to engage in an authentic scientific investigation (NGSS, 2013) and explore and deepen their understanding of mathematical and scientific concepts (CCSS, 2010).

Incorporating computing skills in students' learning in an informal setting is not a new idea. Learning in informal settings refers to the occasions and situations that exist outside traditional or formal schooling whereby learning is embedded in meaningful activity, builds on the learner's initiative or interest or choice (rather than resulting from external demands or requirements), and does not involve assessment external to the activity (Rogoff et al., 2016). The term informal does not connote that learners' change in behavior that constitutes learning is significantly different from that of the formal setting. Instead, the opportunities and environments where the learning occurs differ from the formal school setting or the day-to-day school's designs (King & Dillon, 2012). In other words, the change in behavior that results from learning experience is the same whichever settings it occurs (King & Dillon, 2012). In the context of computational thinking, studies have taken place in several informal settings, such as after-school settings that still share traits with classroom settings (Bentol et al., 2017). Similarly, this study was carried out in an out-of-school setting (summer camp), where the activities are independent of the class curriculum, age, or grade (Adeolu, 2020).

While doing mathematical modeling-related problems in an informal setting, Peck et al. (2020) found that learners can use some community-based practices such as practical wisdom (experience from the community), trying things out and adjusting, and making use of their network of resources (such as peers, facilitators, Google, organizations, etc) when solving problems. These community-based problem-solving practices in mathematical modeling (Peck et al. 2020) are relevant when learners exhibit computational thinking practices in an informal setting. The facilitator in this study designed the agent-based modeling task to allow participants to use the community-based practices to analyze, interpret, and evaluate computational models and when writing codes in NetLogo.

Research Questions

To achieve the purpose of this study, I explore two research questions: How do learners interact with peers, facilitator, and computational tools to construct computational thinking practices? What computational thinking practices do learners construct during their interaction with peers, facilitator, and computational tools?

Theoretical Perspective: Social Constructivist Theory

Constructivism is the theory that says learners construct knowledge rather than just passively taking in information (Sobels, Szili, Bass, 2012; Adams, 2006). This study is situated in the social constructivist theory (SCT) propounded by Lev Vygotsky (1978). To Vygotsky, social interaction plays a crucial role in the process of cognitive development. As people participate and experience the world and reflect upon those experiences, they build their representations and incorporate new information into their pre-existing knowledge. In this sense, Lev Vygotsky (1978) situated the world experience in social interaction and emphasized the importance of interaction with people and tools such as language and computers to mediate knowledge construction. He discussed the relationship that exists between mediational means, subject, and object. In his work, he used the concept known as the mediational triangle to show the relationship between the three (Vygotsky, 1978).

To a social constructivist, learning is a process whereby social influences and interactions with others play significant roles in assuring that learners enculturate into a community of practice and during this process, learners generate the ability to advance and cultivate a shared meaning, thereby transferring knowledge to the group members (Wenger, 1998). Social constructivist theory presents itself as a useful tool in how the activities used in this study were developed and enacted to help learners to co-construct knowledge. Knowledge construction happens when learners build on a network of people's prior knowledge and experience as applicable to the task at hand. The prior knowledge as regarded in this study could be mathematical knowledge, knowledge of coding, or the community-based practices that learners exhibit during interactions with other learners, facilitator, other adult mentors, and the computational tools. Results from the study extend the field's knowledge about social constructivist theory in relation to developing computational thinking practices in informal setting.

Methods

This present study is a part of a larger project focusing on rural youth learning to use mathematical modeling to investigate issues in their immediate environment and in their home communities. In the study, twenty-nine youth and nine adult mentors from six rural communities participated in a summer camp where they worked on modeling activities. While at camp, all participants worked with the facilitator to simulate disease spread in an unplugged situation (without a computer) and in NetLogo. After the whole-camp activity, a few youths continued to explore agent-based modeling during an elective session (Table 1). In this study, I report the case of five youth and one adult mentor from the Waterside group, two camp staff, and one instructor (Table 2) working together to advance their knowledge of agent-based modeling during an elective session. I also present these participants' involvement during the whole camp simulation of disease spread using NetLogo.

Data Collection

Video recordings of the focused group during the whole camp and elective sessions are the primary data sources for this study. As part of the research group on the larger project, I took part in setting up the video recordings and participated as project staff throughout the camp - allowing me to work directly with the youth. I focused on the Waterside group because the members participated in both the whole camp and the elective activity sessions that were focused on agent-based modeling (Table 1). I also controlled the music during the unplugged situation to allow participants chicken-dance around during the disease spread.

Data Analysis

As a research team, we developed the content log for the video data. Subsequently, I identified places where participants were interpreting, evaluating, and exploring the computational model or places where they were manipulating codes in the content log to develop the transcripts and the transcripts were analyzed. To answer research question 1, I used the interaction analysis procedures (Jordan & Henderson, 1995; Schütte et al., 2019) to reconstruct how individuals' computational thinking practices were interactively developed, becoming shared-ideas within the group and consolidating individual learning for participants. For research question 2, I read through the data corpus on the level of meaning (DeCuir-Gunby et al., 2011) to identify lines, sentences, or paragraphs that describe instances when participants engage in practices that allowed them to analyze, interpret, and evaluate a computational model or make a block of code to run. I then assigned codes (labels) to the identified data units (Miles, Huberman, & Saldaña, 2014). Table 3 (Appendix) and Table 4 respectively show examples of interactional structure units - themes that emerged within the group as they worked on the task (Schütte et al., 2019) – and transcripts of selected sequence. In Table 4, examples of data-driven codes identified across the "all campers and elective sessions" are displayed alongside data units. Table 5 shows the definition of these data-driven codes.

Table 1

Description of Agent-Based Modeling Activity at The Summer Camp

Task	Session	Description	Purpose
Agent-Based Modeling	**All Campers**: The activity models some complex systems in the world. For example, modeling a population involving healthy and sick people and how the system evolves with time. The instructor and learners direct the activity.	Youth and adult mentors followed the directives of the facilitator to simulate disease spread. Each person was designated a status (susceptible or infected) at the beginning of the activity. Participants (all groups) chicken-danced around, stopped when the music stopped to play the rock-paper-scissors game. The loser (if susceptible) becomes infected if the winner is a carrier of the virus and the music goes on again. This natural simulation continued until participants began to see patterns and made predictions under different scenarios the facilitator had considered. After this game, the facilitator opened the disease spread in NetLogo to model the complex situation the participants had just experienced in an unplugged situation. During the NetLogo simulation, participants were seated in groups, thereby allowing data collection for the Waterside group through video recordings.	To investigate how a technology-based approach could be used to model a real-life scenario, such as NetLogo, to model sick and healthy people.
	Elective: Participants work with the instructor to write codes to create turtles and patches in NetLogo. The facilitator and learners direct the activity	During the "all campers session," participants had worked basically on what the facilitator set for them in the NetLogo program. During the elective, The Waterside group worked together to edit/manipulate codes that create turtles and patches in NetLogo. Sometimes they mimicked codes provided by the facilitator, adjusted to make it theirs. This activity allowed participants to make assumptions, unlike when the facilitator had made assumptions about everything that went into the model. The primary focus of this activity was to enable participants to create models that would incorporate their reasoning. For example, how the initial infected and susceptible population would affect disease spread model.	To learn how to write code that would create scenarios similar to what they have experienced during the "all campers" learning

Table 2

Descriptions and Roles of Participants in This Study

Participants	Description	Role in this study
• Max (M) • Jasmine (F) • Connor (M) • Kayla (F) • Maria (F)	Youth from the Waterside community. They are all whites, age range of 12 to 14, middle schoolers attending the same school, and they are also members of the 4-H group in their community. 4-H is a youth development organization that provides youths community, mentors, and learning opportunities to develop skills they need to create positive changes in their lives. The program allows youths to come together to work on projects that are beneficial to them and their communities.	They represent the learners in this study.
• Fiona (F)	Fiona is the leader of the 4-H group the youth belong to. She is white and works for the local government in the community.	She is sometimes referred to as a chaperone or adult mentor, and her role was to guide the learners and contribute her ideas.
• Sally (F) • Debby (F)	They are camp staff who received training a week before the camp was held in the summer of 2019. Sally was an undergraduate of Mathematics Education at the time, while Debby is a Statistician.	They supervised the activities of learners in the group. They also contributed when necessary.
• Facilitator (M)	A PhD holder and university mathematics teacher educator. He is a Co-PI on the larger project.	Designed and implemented the activities during the summer camp.

Table 4

Examples of Content Log/Transcripts

	Time	Content log/transcripts
All Campers This activity was preceded by chicken-dance to	1 (52:00 – 55:20) 2 3 4 5 6 7	The facilitator gathers everyone’s attention. He introduces the computer tool that helps simulate situations - NetLogo. He says he wants to just get into it, he wants to “try it.” He hits the set-up button and asks them to talk in their groups about what they notice and what they think just happened. Connor says the red are the sick people and the white are the healthy people. Jasmine says they are randomly dispersed. Connor agrees. Kayla asks if it says how many people there are. Connor asks the facilitator how

simulate disease spread in an unplugged situation		many people there are. The facilitator says 300. One of the adult mentors exclaims, “really?”	
	1:05:30 – 1:06:45	The facilitator asks participants to think about what the left graph is keeping track of. Connor mentions the red line is the percentage sick and the green is the percentage healthy and explains why they would mirror each other. Jasmine asks if everyone has gotten sick how can there be healthy people. Connor mentions they have a recovery time. Max says that the average seems to be 25 but that the maximum is 50 for recovery. Sally explains how the slider works.	Model interpretation and connection to real world
	1:06:45 – 1:09:02	The facilitator brings the group back together, stated that they need representations of what they are noticing and what the graphs do. He asks Connor to share. Connor talks about the left graph - the green is healthy and the red is sick and he talks about why the graph is doing what it is doing.	
	1:16:05 – 1:17:44	The facilitator recollects everyone and asks what everyone notices and what happened. The facilitator asks if this is what they predicted. The facilitator states that no one told them to make this graph (someone whispers, “like the birds”), but they just walked around like we did outside. There are simple rules that people follow, but bigger patterns emerge. He makes a prediction that there would be some jaggedness in the graph but asks what percentages there would be overtime. Connor says the disease dies down. The facilitator asks the group, if we were interested in public health but we could only focus on one thing, reducing transmission rate or recovery time, which should we focus on? Connor says transmission rate, because if you leave the recovery time but decrease transmission rate, then less people will be getting sick and more people will be recovering. He mentions that if you do the other then you will be getting better faster but will turn around and get sick again. Jasmine says she has a problem with everyone getting sick because that doesn’t always happen. That she has been around a bunch of sick people, but she wasn’t sick.	Making conjectures and generalizing Model interpretation and connection to real world
	1:17:44 – 1:20:55	The facilitator recollects everyone and states that he does the mathematical practice of “work systematically.” He will only change one thing at a time and keep everything else the Same. The facilitator changes the average recovery from 50 to 10. Asks them to think about what will happen. The facilitator goes back to the original world but changes the transmission rate to 10%. People watch the simulation. Jasmine clarifies which was	Parameter manipulation and discovery

		Connor's prediction. Jasmine mentions that is almost the Same thing. Jane mentions how it goes back and forth more often. Connor says, "So they are just going through more pain." Max says that healthy is always winning. He mentions that the more healthy the more likely they will get sick, the more sick the more they recover. Jane comments that Connor was totally right and she was wrong. Max says they just had enough time to heal before they could infect someone else. He also mentions that if they ran it again this would look different. He mentions that they will all eventually get healthy, but other parts of the simulation will look different because of the randomness of certain things. Sally asks what they thought would happen if something changed and Max made a prediction.	Making conjectures and generalizing
Elective Prior to this time stamp, the facilitator allowed participants to open different models (e.g., traffic model) in NetLogo program to make participants get sense of various capabilities of the program	(18:09 – 25:00)	The facilitator tells the youth to make a new file to create a blank work. He tells them that they are only going to make a sheep and grass world, but they can add wolf if they want. He explains how to create the set-up button by using the add button. Kayla notices that it does nothing. The facilitator says so far, they've made a button which they'll call set-up. Connor asks if it's through the display. The facilitator mentions that they should go to command. He explains that the button should be red when they press ok. He further explains that it's red because computer has not been informed on what to do with the button. Connor asks if they will be able to move it and the facilitator says yes. The facilitator notices that Kayla gets it. At 20:28 The facilitator says they need to tell computer what the button should do. While Connor and the two girls are super excited about what they are doing and achieving, Max is not saying much but appears to be getting stuffs done. At 20:56, The facilitator says he would write some code on the screen and tells the youth to do likewise. All the group members are engrossed in typing the code the facilitator puts on the screen. Fiona also gazes at the screen and looks at what Connor is typing. The facilitator waits a bit and at 23:12, he asks youth what they think would happen if they press set-up. Connor –it's going to work. Kayla –it's going to create turtles. The facilitator–how many turtles? Kayla –3. Connor & Maria –100; Kayla –yea. The facilitator –yea, 100. Connor's code doesn't work but realizes he forgets to use hyphen somewhere in the code. Connor does that and the code works. At 23:48, Kayla excitedly says -it works! At 23:55, Maria couldn't get it work, raises hand to get the facilitator's attention. The facilitator comes over to check her code while Maria pays close attention. The facilitator figures it out and it appears that	Prompting and exploring

	she understands instantly what the problem was. She then presses set-up and the code work.	
(31:00 – 36:00)	Max asks the facilitator something about movement (inaudible), The facilitator says yes. He remarks that “now the turtles move around” but not continuous. He explains what they would do to make the turtles go on forever when they click the GO button. The youth exclaim that it is moving too fast. Connor remarks that they need to make the turtles appear like sheep. The statement draws the attention of the facilitator and asks how they can achieve that. Connor says, “set turtles”, Max says “ask turtles”. Connor immediately says, “ask turtles set shape”. The facilitator agrees with their thinking and wants to try it. He explains where they can go to do that –the set-up. The facilitator writes code as suggested by Connor. The facilitator remarks that nothing named sheep has been defined. He suggests they put sheep in quotation marks and remarks that he’s just experimenting. At 34:08, Kayla excitedly remarks “yes, they are fish.” “Why would you do that”, Connor asks. The facilitator asks what she does to make them fish. The facilitator remarks that experimenting is very good, the world never ends if it doesn’t work. Connor achieves chicken, and others are now achieving different shapes. One of them remarks that there’s no human. After few seconds, the facilitator tells them to try “person.” The facilitator tells them that they can always browse the internet to get what they need when coding. For example, “NetLogo shapes.”	Parameter manipulation and discovery
(36:00 – 41:58)	At 38:05, the facilitator remarks that there seems to be a way they can create their own shapes. At 38.11, Connor asks what else they can do; like expanding, he says. The facilitator says ok, let’s expand this one. The facilitator moves the code to the set-up button. He remarks that the next thing to do is to set up the patches. They write code to set up the patches. The facilitator remarks that the shape of the patches cannot be changed but the color can be changed. At 41:25, Connor exclaims that he achieves error. The facilitator tells him to see if he can troubleshoot his errors.	
(41:58 – 45:46)	Maria raises hand to signify request for the facilitator’s assistance. Kayla appears super engaged with coding. At 43:04, Kayla achieves something the facilitator could see as he helps Maria. The facilitator gives thumbs up to Kayla while she gives a sign of self-admiration for her accomplishment. At 43:21, the facilitator suggests that Maria looks at what Kayla has done. At 43:28, the facilitator returns to his computer while Max asks if someone	Prompting and exploring

can generate random numbers. The facilitator says he can do random-100 to obtain random number between 0 and 100. Connor picks it up from there with a question (43:55) that the facilitator considers interesting. Seems like Connor wants to generate 200 random number with some portion (100, maybe) to sheep and 100 to wolves. The facilitator remarks that he will show them how to achieve that. At about 44:00, it becomes clear that Kayla is putting Maria through some coding stuffs as they look at their computers. At 44:11, the facilitator comes over to Connor to experiment what he has asked. After looking at the code, the facilitator suggests that Connor tries it (44:28). At 44:37, Fiona looks keenly at Connor's work, then suggests some semantic interpretation of the code. Fiona mentions how the code (not visible) represents coordinates x and y. she suggests that Connor tries it in both ways.

Prompting and exploring

Results

I organized the findings from this study according to each research question.

Research Question 1

How do learners interact with peers, facilitator, and computational tools to construct computational thinking practices?

The facilitator introduced the computational environment to participants by projecting it onto a screen. During all campers' session (Table 1), each group discussed the disease spread model displayed by the facilitator. In the disease spread computational model (Figure 1), the facilitator made choices and assumptions for the model to run in NetLogo, leaving learners' interaction with the computational tool passive [3-8]. In other words, learners only had the opportunity to interpret, analyze, and evaluate the model's output in their discussion. However, during the elective, learners could actively interact with the computational tool. That is, learners had the chance to make choices and decide the kind of exploration they wanted to embark upon, thereby making their interaction with the computational tool active [53-55, 73-76]. During the elective session where learners could actively interact with the computational tool, participants relied on the instructor to start navigating the NetLogo environment.

At the initial stage, no participant showed any significant prior knowledge of NetLogo or of agent-based modeling. As soon as the facilitator set the stage, learners and adult members first made sense of the situation to form individual ideas and then used questioning to interact within the group. The facilitator also posed questions interact across groups during the all campers' session and within group during the elective session. The nature of the interactions during all campers & elective sessions is discussed under the subheadings Individual-Group Interaction and Whole-Group Interaction. The subsequent paragraph discusses how questioning helped the interactions.

Figure 1

Computational Model for Disease Spread

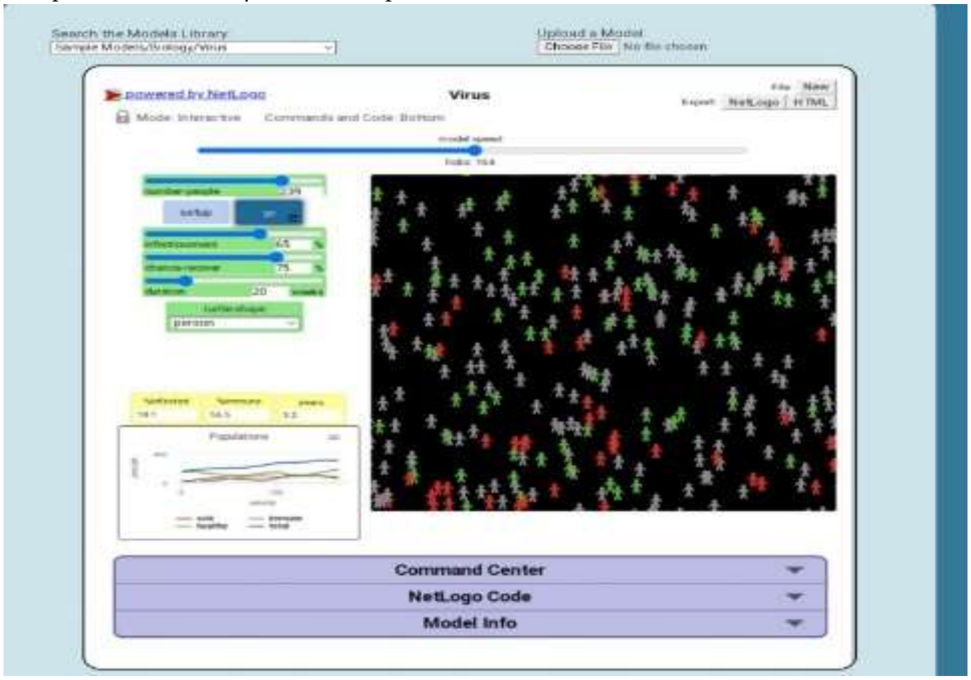


Figure 1 shows the NetLogo interface for a virus spread. The dark portion shows agents that are sick (red), healthy(green), or removed (grey) from the system. The sliders to the left of the agents are the model parameters that the user can vary to change the interactions in the model. Below the model parameter is the graphical representations of the interactions (Wilensky, 1999; Tisue & Wilensky, 2004).

Individual-Group Interaction: Here, group members responded to a prompt from the facilitator, peers, an adult mentor, or camp staff. At the initial stage in the disease spread, each group member took a turn to discuss the computational model's interpretation, analysis, and evaluation [9-14]. Each learner observed the computational model, talked about their observations, and sometimes asked questions about the model. The discussions led to an argument, agreement, disagreement, or confusion within the group(s). For example, in the disease spread model, while Fiona and Jasmine talked about how everyone has been sick, Max stated that everyone would not get sick. Later in the discussion, Jasmine stated that she had a problem with everyone getting sick because that does not always happen [2-6, 26-34]. During the discussion, group members used community-based practices to justify their interpretation. For example, Jasmine used practical wisdom (community-based experience) to state that she has been around many sick people, but never got sick, so she agreed with Max that everyone would not be infected [31-35].

During the elective session, learners mimicked blocks of codes written by the facilitator, ran them, and discussed the outcome. To do this, they asked questions to understand further their conjectures or what they needed to do to enable the blocks of codes to run [65-79]. The adult mentors in each group sometimes helped learners better communicate their ideas to other members within the group [14-15]. They also raised concerns about what a learner has said, leading to further discussion within the group. The exchange between Jasmine, Fiona, and Max exemplifies situations whereby participants exchanged ideas with a flavor of argument and disagreement. By engaging in group discussion, participants could share ideas about their interpretations and evaluation of the model. The adult mentor ensured that ideas are refined and accommodated within the group. The presence of adult mentor(s) in the group allowed participants to respect other people's views.

***Whole-Group Interaction*:** Here, during whole-group interactions, group members interacted across groups by having a representative from each group shared what they had discussed during the *individual-group discussion* [16-19]. Sharing helped the facilitator understand how or what the groups were thinking about during the individual-group interaction. The facilitator could then clarify any misconceptions that ensued from a particular group and generalize ideas presented by different groups [20-26]. Moreover, intergroup exchanges of ideas allowed groups to access interpretation, analysis, and model evaluation from perspectives of other campers and see features of the model they did not consider during the individual-group interaction. For example, before the whole-group interaction, the Waterside group had not mentioned anything about the graph or connected it to their model interpretation. However, as soon as a representative from another group mentioned it, Connor started talking in the Waterside group about how the red line would represent the percentage of sick people, and the green would represent the percentage of healthy people [9-11]. This kind of discussion was not limited to the Waterside group; other groups that are not the focus of this analysis did the same.

The whole-group interaction allowed the facilitator to push all groups to explore more within their groups. For example, when a representative from a group talked about the left-hand graph and the mirroring relationship with the healthy and the sick, the facilitator then asked all groups to discuss what the left graph was keeping track of. This further discussion led to different groups making new conjectures and raising new questions about the model. For example, when Connor talked about the red and green lines, one group member asked how healthy people could be if everyone had gotten sick [12]. The section below details how *questioning* was resourceful in initiating interaction between group members, the facilitator, and the computational tool.

Questioning: Was used to keep the interaction alive within and across groups and to promote deeper interpretation, analysis, evaluation, and manipulation of the model. Questions have long been used as a teaching tool by teachers to assess students' knowledge, promote comprehension, and inspire critical thinking (Tofade et al., 2013). The facilitator in this study used both high and low cognitive dimension questions (Tofade et al., 2013) to push participants to space that allowed them to analyze, deduce, choose, contrast, compare, and distinguish ideas constructed within the group [9-15]. In the interactional data unit [9-15], the facilitator's question about what the left graph was keeping track of, propelled participants to engage in creative thinking that promoted comprehensive exploration of the model and led to new insights. Tofade et al. (2013) assert that questions promote deep thinking, requiring learners to analyze and evaluate concepts. In this study, participants and facilitator used question types (Tofade et al., 2013) that are divergent (open and having many responses [9-15]), focal (allowing participants to justify a position [75-76]), brainstorm (questions that generate a list of ideas or viewpoints [69-73, 85-88]), and convergent questions (closed, not offering many options [113-114]) to drive meaningful discussion in both sessions. Using questions enabled participants to connect the computational model to their world. For example, Sally, a camp staff, asked if everyone would eventually recover. Max replied that if it were chickenpox, one would be immune after recovery.

In sum, the analysis of data shows that learners can interact in small groups (individual group) to develop computational thinking ideas. During the individual interactions, each learner discussed their initial ideas which either led to general acceptance by other members or raised questions that prompted further discussions and explorations. They interacted with other groups (whole group) to have a rethink of their initial conjectures or developed a totally new idea about the model. During any form of interaction, they relied on the expertise of the instructor or adult mentors to clarify and authenticate the ideas building up. Learners, adult mentors, and facilitators used different kinds of questions to keep the interactions alive and to promote deeper interpretation, analysis, evaluation, and manipulation of the model/code.

Research Question 2

What computational thinking practices do learners construct during their interaction with peers, facilitator, and computational tools?

During interaction with peers, facilitator, and computational tool, data show that learners engaged in some practices specific to exploring the computational model and writing codes in NetLogo. Learners engaged in model interpretation and connection to the real world, parameter manipulation and discovery, posing computational questions and exploring, and making predictions/conjectures and generalizing.

Model Interpretation and Connection to the Real World: Describes when participants explained what they observed on the computational model in the context of the task at hand and made connections to the real world. In some situations, they used community-based practices such as practical wisdom (experience) to interpret or describe their observation of the model. For example, when Connor gave conjectures about leaving the recovery time but decreasing transmission rate that fewer people will be getting sick and more people will be recovering, Jasmine stated that she had a problem with everyone getting sick because that is not always the case as she has been around sick people without getting sick [31-35]. Learners read and gave interpretations of their observations of the computational model and strived to relate their conjectures to events around them. The objects of the model, such as the agents and the generated graphs, became artifacts learners interpreted, analyzed, and evaluated in the context of the real-world problem.

Prompting and Exploring: Describe instances whereby learners and facilitator posed questions and explored through the computational tool. Data show that the facilitator mostly used questions to invite learners to participate in interpretation, exploration, discovering, conjecturing, and generalizing the computational model during the *all-campers* session (Table 1). Also, learners were active users of questions to explore many opportunities they deemed fit as they interacted with NetLogo and other participants. Sometimes, the facilitator would ask questions to allow learners to experiment further or explore the computational model or their code. For example, when Connor remarked that they needed to make the turtles appear like sheep, the facilitator asked how they could achieve that, and that pushed all learners writing codes to explore how they could change the turtles to appear like sheep [84 – 88]. In another instance, Max asked how someone could generate random numbers while the facilitator explored and made suggestions [112 – 116]. In a sense, learners can raise questions that will require the facilitator to explore or invite other learners to explore [116 – 119].

Parameter Manipulation and Discovery: Describe instances whereby participants manipulated the computational tool and made some discoveries through the manipulations. The facilitator had the sole opportunity to manipulate parameters while learners just observed during the disease spread model in NetLogo and thereby limiting the learners' discoveries to the choices already made for them. However, learners could manipulate parameters, write codes during the elective session, and make discoveries based on their manipulations. Students' access to personal computers during the *elective* allowed them to be self-reliant as a group and as individuals, mostly independent of the facilitator. Learners experienced a level of difficulty at the beginning of the coding session. At this early stage, the facilitator provided codes while learners wrote the same code on their workstations by mimicking the facilitator's code. However, the tension of what to do and how to do things reduced as learners became more familiar with how things work. The use of *questions* became a viable tool for both learners and facilitator. While learners used questions to understand what they would do and what could be achieved on their workstations, the facilitator used questions to push them to write codes and challenge them to think about the computational model deeply.

The opportunity to try model interpretation, evaluation, analysis, and manipulation on their own propelled the learners to discover ideas themselves. For example, after creating turtles and patches and setting them to wolves, sheep (turtles), and grass (patches), the facilitator noticed how Connor had changed the color of the patches to pink. The facilitator queried how Connor could change the color of wolves to pink without changing the color of the sheep. Instead, Connor changed the color of the sheep to black. In a sense, learners developed different conjectures when they experimented with codes [84-88]. In this situation, exploring computational tools set the learners up to develop a thought process to discover ideas independently that could lead to further exploration or better understanding.

In some cases, the facilitator would consider and try out what the learners had suggested. This collaborative experimentation with the learners' ideas led to further discoveries of how learners interpret, evaluate, analyze, or manipulate computational models and codes. For example, when the facilitator was writing the code as suggested by Connor and Max, they found that nothing named sheep had been defined in their workstations. The facilitator then came up with suggestions such as putting sheep in quotation marks. While trying to figure out how to make sheep, Kayla discovered how to make the turtles appear as fish [89-99]. Experimentation or trying something and adjusting is a valuable tool when learners were writing codes. In this sense, there is an overlap between the community-based practice of trying something and adjusting and the computational thinking practice of parameter manipulation and discovery. The facilitator made this known to the learners that the world would not end if things failed to work as intended. He further stated that they could browse the internet to look up stuff when writing codes [97-99] to help their experimentations.

Conjecturing and Generalizing: Refer to scenarios where learners predicted what would happen based on their interpretation, manipulation, discovery, and exploration of the codes or the computational model to make generalizations. For example [26-35], when the facilitator invited learners to focus on reducing the transmission rate or recovery time, Connor conjectured that reducing the transmission rate would be ideal. If you leave the recovery time but decrease the transmission rate, fewer people would be getting sick, and more people would be recovering. However, if you went otherwise, people would get better faster but turn around and get sick again. Although all the group members pushed back on Connor's idea, as Jasmine stated that she had been around sick people and was never sick, the facilitator's suggestion that they experiment with the two scenarios allowed all group members to understand Connor's conjectures [38-42]. In other words, the facilitator assessed learners' conjectures and generalizations, made pedagogical suggestions to clarify any misconceptions or help learners better understand their interpretation, manipulation, discovery, and exploration. Thus, when the facilitator increased the transmission rate, based on Connor's conjectures and Max's interpretation of the effect as seen on the facilitator's screen, Max generalized that the more healthy, the more likely they would get sick, and the sicker, the less they would recover [44-46]. When the facilitator decreased the transmission rate to 10%, Max stated that the sick just had enough time to heal before infecting someone else and thus conjectured that things would look differently if they reran the simulation [47-51]. He mentioned that the sick would eventually get healthy, but other parts of the simulation would look different because of the randomness of certain things.

Modeling Learning Through Interaction

Analysis of data shows that learners can interact to contribute individually within the group to develop ideas needed to interpret, evaluate, analyze, or manipulate computational model. During the individual and whole group interactions, learners discussed their ideas and listened to ideas from other group members to inform and refine the initial conjectures and understanding they made about a computational model. When learners engaged in coding, ideas from other members also strengthened individual ideas and helped them reason and proceeded with the coding exercise. Schütte et al., (2019) referred to individual ideas as the individual processes of interpretation that learners develop. These individual processes that are transformed and stabilized in the exchange with other individuals become collective processes that help learners learn something new (Schütte et al., 2019). In this study, the refined ideas became learners' new interpretation and evaluation of the computational model. These refined ideas provided foundations for learners to manipulate and explore the computational tool to build a better model or write a better code. In other words, learners are developing concepts to become more central participants in how they further relate with the computational model or coding. The refined ideas also helped the facilitator to have a better understanding of learners' interpretation, evaluation, and analysis of the computational model/code. Likewise, learners had the opportunity to exchange ideas beyond their group. In this sense, group members listened to ideas presented by other groups. Such opportunity afforded the listening groups the opportunities to develop new ideas or build on the ideas they have at hand. This study also shows that adult mentors and the facilitator are responsible for ensuring that the refined ideas are meaningful in the context of the task. That is, the authenticity of the refined ideas that constitute new learning is supervised by the adult mentors (during individual interaction) and the facilitator (during the whole-group interaction).

The implication for teaching and learning is that teachers should endeavor that individual groups come to refined ideas within their groups and share with the classroom to assess the authenticity of the collective ideas. In practice, learners should be allowed to develop individual ideas followed by collective ideas through individual group discussion. Furthermore, these refined ideas should be shared with the other groups to encourage quality ideas across all groups.

Figure 1

Shows a typical interaction during the individual group interaction.

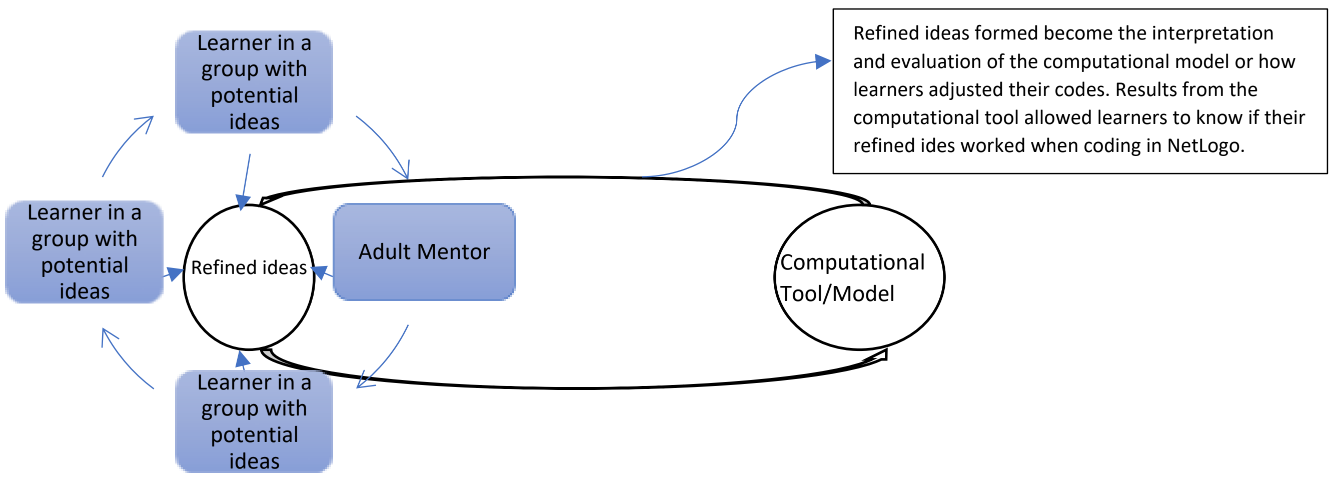
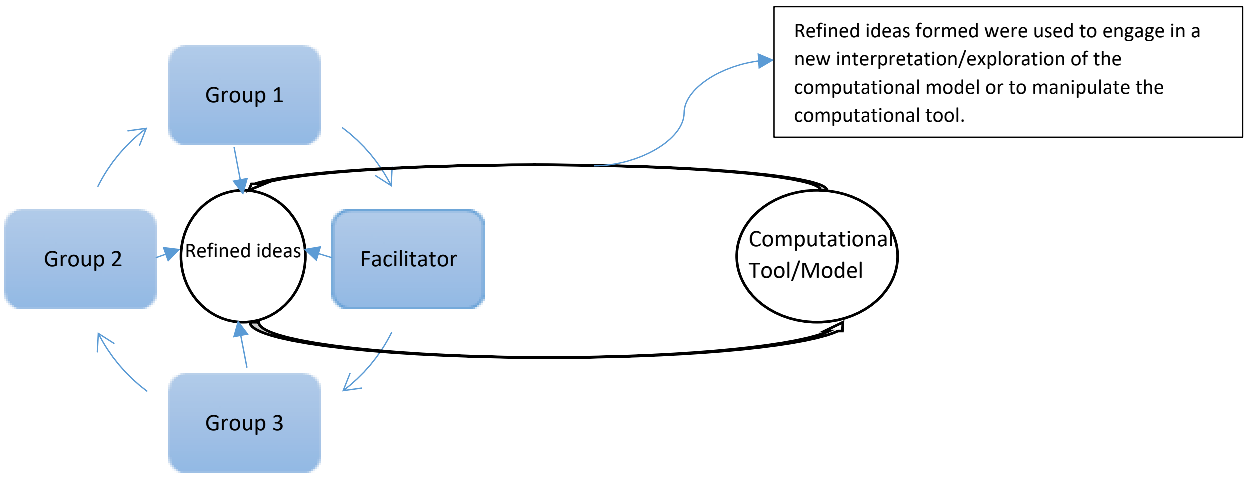


Figure 1: During the Individual-Group Interaction, learners develop refined ideas about the interpretation of the computational model or use the refined ideas to manipulate and explore the computational model.

Learners and adult mentors interact within the group mainly through questions that according to Tofade et al., (2013) prompted critical thinking to probe the ideas flowing within the group. Learners in each group continue to interact with the computational model based on the collective (refined) interpretations, analysis, and evaluation developed during discussion to formulate new ideas in interpreting the computational model or writing codes. Sometimes a group member would raise objection to the newer interpretation, or the codes would not run as they intended. This process continued iteratively until learners were satisfied that the refined ideas correctly gave interpretation of the model or achieved a successful code block. Sometimes, the process came to abrupt pause/end when the facilitator called on each group's representative(s) to discuss their findings. Questions that allowed learners to engage in deep thinking were useful to promote interactions that led to refined ideas. Figure 2 shows the interaction that occurs during the whole-group interaction whereby representative(s) from each group shared ideas with the other groups.

Figure 2

During the Whole-Group Interaction, Learners Listen to Refined Ideas Presented by Other Groups to Gain New Insights or Build on Their Developed Ideas.



Conclusion

Results from this study agree with Vygotsky's (1978) relationship that exists between mediational means, subject, and object. In his work, he used the concept known as the mediational triangle to show the relationship between the three. In this study, I found the relationship between learners, computational tool (mediational tool), facilitator, and adult mentors as a significant input in learners' interaction and construction of computational thinking practices. Through discussions with others within and across the groups, social influences and interactions ensure learners enculturate into a community of people constructing computational thinking practices. This study notes that the level of interaction between learners is inversely proportional to the facilitator's influence when computational activities are ongoing. The more influence the facilitator has on learners in computational modeling space, the less learners would be able to be independent, thus reducing their level of interactions among learners. It would be wise to encourage facilitators to use the reciprocal strategy, a form of scaffolding and withdrawing, to allow learners to construct meaningful computational knowledge themselves. This idea corresponds to Adeolu (2020) suggestion that the facilitator should act as a coach and not an actual player in the modeling space. A facilitator can promote interaction between learners by not giving direct help. Instead, facilitators may call on other learners to share their computational ideas with struggling learners.

The analysis shows that learners can interpret, analyze, evaluate, make conjectures and generalize a computational model when the facilitator solely has the opportunity to manipulate the computational tool. Thus, learners do not have the opportunity to exhibit practices such as defining problems, making assumptions, constructing models (Stephens, 2019 & Stacey, 2006), abstraction, algorithmic thinking (Selby, 2015; Weintrop et al., 2016). However, learners tend to exhibit these practices when they have the opportunity to manipulate and try things out when using computational tools. In addition to the above opportunities, they would be able to explore and discover things by themselves. This study also reveals that learners come to computational modeling space with some background knowledge they acquired through their involvement in the community. Learners can use community-based practices such as practical wisdom to interpret, analyze, and evaluate the computational model. The community-based experience also allows learners to quickly connect between computational models and the world they live in. This result emphasizes the need to engage learners in modeling activities that resonate with their day-to-day experiences. In addition to making their learning authentic, it strengthens the relevance of learners' world to the classroom world

When learners write codes or manipulate computational models, they develop conjectures that drive their coding abilities further. Thus, facilitators do not necessarily need to know all; they can seek learners' ingenuity and try it with them. This study also finds that learners are significantly engaged when tasked with the opportunity to try model interpretation, evaluation, analysis, and manipulation independently. They always want to try out challenging ideas in writing codes and see if that corresponds to the derived outcomes. Sometimes, the facilitator must inform learners that it is ok not to get a well-running code since such failed experimentation would not end the world. As the NGSS (2013) and CCSSM (2010) place a new emphasis on using or interpreting models, creating models, critically interrogating their limitations, and simplifying assumptions (Weintrop et al., 2016), learners must become part of the processes that give a certain computational outcome. The facilitator should make the decisions, choices, and assumptions that go into the model and cooperate and agree with learners. Such democratic knowledge of what goes into the model would enable learners to give a more authentic interpretation and a stronger connection to the world. In addition, when learners make choices and assumptions, they tend to discover what works and what does not. Although they may initially show some frustration and struggles, such opportunity drives them to want to know more, potentially increasing their scientific curiosity.

Questions that promote deep thinking are a vital pedagogical tool that drives learning on the part of learners and the facilitator's teaching. Facilitators should be ready to take up learners' curiosity, explore, and then learn together rather than limiting learners to computational knowledge they could gain from them. Also, when learners engage with computational models, they are positioned to make conjectures and predictions. Sometimes, these conjectures and predictions are derived from learners' community-based experiences, such as how the disease spread among animals. The opportunity to interpret, analyze, and evaluate a computational model enables learners to relate the learning experience to their world. Thus, creating a space to connect formal and informal learning experiences and therefore becoming a more informed citizen of the world. Since each learner's experiences differ, the possibility of making different conjectures and predictions sometimes may lead to confusion for other group members. Therefore, a facilitator must be much equipped to handle situations that arise in the moment as no facilitator could envisage and prepare for what would happen beforehand. However, facilitators do not need to be an expert to facilitate modeling involving computational thinking practices as they can also learn with learners in the process. That is, it is okay if facilitators don't anticipate every idea a learner might develop in the process. In fact, this is impossible! However, data suggests there is opportunity when learners and facilitators explore ideas together because the facilitator can make their process for working out an idea visible to the learner. In other words, the facilitator may be modeling computational thinking for the learner as they work together. Nevertheless, the facilitators need to know where and how to look up stuff (e.g., googling NetLogo shapes) to navigate any difficult or strange instances during their facilitation.

This study reveals that practices some studies (e.g., Selby, 2015) have identified with mathematical modeling and mathematical thinking also manifest as important computational thinking practices. These practices include interpretation, connection to the real world, and generalization. In addition, this study finds practices such as parameter manipulation, discovery, prompting, model exploration, and conjecturing/making predictions as practices that learners exhibit when engaged in a computing-related modeling situation. Although this study was carried out in an informal setting, the practices found in this study might be similar in a formal setting; however, studies need to be conducted to assess the assertion. As the change in behavior that results from experience is the same in formal and informal settings (King & Dillon, 2012), I recommend that researchers, facilitators, and other stakeholders pay close attention to results from this study. Furthermore, this study supports Peck et al.'s (2020) findings that learners use some community-based practices when solving problems. In this study, I found that learners use their community-based experiences such as practical wisdom (experience), making use of their network of resources, and trying something and adjusting to support their interpretation, model connection to the real-world, conjecturing, and generalizing.

In conclusion, findings from this study can inform researchers on computational thinking practices that learners exhibit when working on agent-based modeling and when writing codes in NetLogo. The findings will also inform researchers and facilitators on the roles of facilitators in such teaching space. Results from this study also reveal the kind of interactions that learners engage in when constructing knowledge in social settings. Future studies should consider learners as part of the decision-making process when making choices and assumptions about what goes and what does not go into the computational model. This study shows an overlap between some community-based practices and computational thinking practices, this necessitates a thorough investigation to learn more about the overlap and the opportunities it presents for learning. Furthermore, future studies should consider other forms of computational tools (e.g., Python, Scratch, CODAP, etc.) to investigate if the practices found in this study apply in other situations. The results presented in this study is limited to interactions captured on video recordings. Thus, future study should consider conducting a stimulated recall interview with participants to gain better access to their interactions and the development of computational thinking. Although this study reported on what the facilitator was doing to help learners navigate the task, intensive study needs to be conducted to document the roles of facilitators when learners are developing computational thinking practices. The types of questions that help learners develop computational thinking practices should also be extensively studied.

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