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Computational Thinking through Body and Ego Syntonicity: Young Children's Embodied Sense-Making Using A Programming Toy

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Abstract: Papert's concept of body syntonicity (how an experience aligns with learners' sense and knowledge about their own bodies) has been embraced by learning scientists; however, his notion of ego syntonicity (how an experience aligns with children's sense of self as people with intentions, goals, desires, likes/dislikes) is less discussed. We argue body syntonicity (BS) and ego syntonicity (ES) are both critical dimensions for understanding how young children learn abstract concepts and skills as part of embodied computational thinking (CT) with tangible programming toys. Using multimodal interactional analysis, we demonstrate how a preschooler (aged 4) used both physical enactment (BS) and intense emotional involvement (ES) with precisely coordinated response cries (e.g., collaborative cheering, gasping) to make sense of how a continuous spatial route can be decomposed into discrete programmable steps. We discuss implications for learning sciences at large and for supporting young children's learning of decomposition and other CT practices.

Introduction

Viewed as "the new literacy of the 21st century," computational thinking (CT) is the systematic analysis, exploration, and testing of solutions to open-ended and often complex problems (Wing, 2011). In addition to its direct application for computer science or programming, CT is also essential to a broad range of planning, critical thinking, and problem-solving situations in other domains such as reading, writing, and arithmetic (Wing, 2006). Given its importance, there are burgeoning, albeit, limited efforts to explore and promote CT in early childhood (ages 0-8; Çetin & Demircan, 2018; Jung & Won, 2018). However, the majority of these studies focus on the feasibility of introducing CT to young children or effectiveness of such efforts (Wang & Choi, under review). As a result, we still have limited understanding of the *processes and mechanisms* through which young children acquire abstract CT concepts and practices.

To address this gap, we investigate how young children (ages 3-4) can participate in the CT practice of *decomposition,* and we adapt Papert's (1980) concepts of body syntonicity and ego syntonicity to make sense of this process. As one of the foundational components of CT, decomposition is defined as breaking down a complex problem into smaller or more manageable parts (Shute et al., 2017; Wing, 2006). For example, in this paper, the participating children were engaged in decomposing a continuous spatial route (moving from "Start" to "Home" and avoiding an obstacle in the path) into discrete programmable steps (attaching different body segments with commands such as go straight, turn left, and turn right) using a programming toy. Decomposition is an important research focus for understanding young children's CT thinking because dealing with different parts of a complex problem all at once may be especially difficult for young children considering their still limited although fast developing memory capacity.

Theoretical framework and relevant literature

Papert (1980) defines body syntonicity as aligning learning tools and experiences with learners' "sense and knowledge about their own bodies" (p. 63), while "ego syntonicity" as aligning learning tools and experiences with learners' "sense of self as people with intentions, goals, desires, likes and dislikes" (p. 63). Embracing Papert's idea that model of learning should "draw on our own behaviors *(i.e. sense of self)*, our own bodies." (p.64), we argue both body syntonicity (BS) and ego syntonicity (ES) are critical dimensions for understanding how young children learn abstract concepts and skills. Both BS and ES can be considered forms of embodied understanding that children have access to.

In the larger learning sciences community, there is broad support for the notion that the body can serve as a key resource for programming and engaging in CT practices. It has been exemplified by the early work of Papert with Turtle Geometry (1980) and the more recent Maker Movement that emphasizes making learning visible and tangible by designing and physically making robotics, textiles, videogames, etc. (Peppler, Halverson, & Kafai, 2016). There are also concerted research efforts to understand how body syntonicity supports and scaffolds learning. For example, Fadjo et al. (2009) found that elementary school children instructed to use their bodies to act out Scratch programming statements outperform those who merely imagine the statements.

Capitalizing on body syntonicity, Berland et al. (2011) developed IPRO "Programming Standing Up," a mobile programming environment where learners use their bodies to simulate and program a robot to play soccer. In this embodied educational programming environment, students overcome impasses by physically acting out their programs and collaboratively debugging them in ways that are not possible with traditional "seated" programming environments. However, while these studies provide useful insights on how body can be used as *physical problem-solving tool*; they have not explored the role of ego syntonicity in students' *affective embodied sense-making.*

There is growing recognition and interest in the broad role of ego syntonicity (ES) plays in the learning sciences. For example, some researchers have foregrounded students' science identity and sense of belonging in the community of practice, and examined how they are developed and how they shape and support science learning (e.g., Kim, Sinatra & Seyranian, 2018; Barton & Tan, 2010; Varelas, Martin & Kane, 2012). Other researchers have zoomed in on how embodied emotion can be a resource for sense-making at a micro moment-to-moment level. In science education, a number of scholars have demonstrated that students' intense affective experiences (e.g., vexation, wonder) can play a central role in driving their engagement and motivation to solve difficult problems both alone and together (e.g., Engle & Conant, 2002; Jaber & Hammer, 2016). In mathematics, Nemirovsky (2011) has demonstrated that episodic feelings (e.g., surprise, enthusiasm, esthetic appreciation) can help learners narratively make sense of and connect together distinct learning experiences. Notably, Nemirovsky argues that embodied experiences of learning cannot be fully understood without attending to their entangled emotional and affective character. Drawing on these studies collectively, we adopt the position that moment-to-moment emotional responses and experiences are likely fundamental to the ways that leaners make sense of STEM practices and their sense of self in relation to the learning tasks and subject areas at hand (i.e., identity). Currently, research on children's emotional engagement and experiences in CT learning (ES at a micro level) or how learner identity (ES at a meso or macro level) is related to CT learning is sorely lacking.

Addressing this gap, our study explores the role of both body syntonicity and ego syntonicity in young children's CT learning. Specifically, we ask the following research question: how can preschoolers use both physical enactment (BS) and intense emotional involvement (ES) to make sense of decomposition in a teacher-guided group coding session? We focus on a classroom's use of a tangible programming toy, and how a focal child first physically enacts a continuous spatial route but misses some steps, and later is able to decompose it into accurate, discrete programmable steps, after he collaboratively narrates the route and engages in precisely coordinated response cries (e.g., collaborative cheering, gasping) with his group. Response cries are "exclamatory interjections that are not full-fledged words" (Goffman, 1978, p. 800) and are used to display emotion in interaction (For example, like surprise (e.g., Oh!) or revulsion (e.g., Ew!)). Response cries can also be used as interactional resources for drawing joint attention to objects and processes (Streeck et al., 2011). In this study, we show how coordinated response cries help the children perceive and recognize a continuous spatial trajectory in terms of discrete programmable steps in order to navigate the tangible programming toy (i.e., in the process of decomposition).

Significance

Understanding the process of how children use decomposition to solve spatial problems can have important implications. Theoretically, by adopting both body syntonicity (BS) and ego syntonicity (ES), our study brings the affective embodied dimension of learning to bear along with the physical body. Thus, our study embraces learner-centered philosophy in its fullest sense. Practically, we argue that understanding how to support both BS and ES may help teachers and parents strengthen young children's learning of CT concepts and practices by leveraging children's knowledge and sense of their body (both emotionally and physically) and motivating them with connections to their own desires and emotions.

Methods

Our present study emerged as part of a larger investigation examining young children's CT learning with a commercially available programming toy at a University-affiliated preschool in the United States. Children worked with Fisher-Price's Think and Learn Code-a-pillar (Code-a-pillar for short) (https://www.youtube.com/watch?v=3d4zXauy6EM) in small groups once or twice a week (average 15 minutes per session) for over 12 weeks. Twenty-two children and two teachers participated in the study. As shown in Figure 1, the Code-a-pillar is shaped like a caterpillar but has interchangeable body segments that program the caterpillar to move and behave in multiple ways. Each body segment represents a different command (e.g., turn right, turn left, go straight, play music). In a purposefully-designed introductory session, children named the Code-a-pillar 'Rapunzel' through a process of brainstorming and voting, decorated a house (a box) for Rapunzel, and learned rules for taking care of her. Each week, children engaged in new programming challenges that often-involved imaginative stories about Rapunzel and required "helping" her navigate to desired locations in the room by programming her. With the teacher's guidance, children engaged in various forms of CT thinking and were encouraged to empathize with the caterpillar's goals (e.g., going home, escaping a toy wasteland). All sessions were video recorded, creating a corpus of about 15 hours.

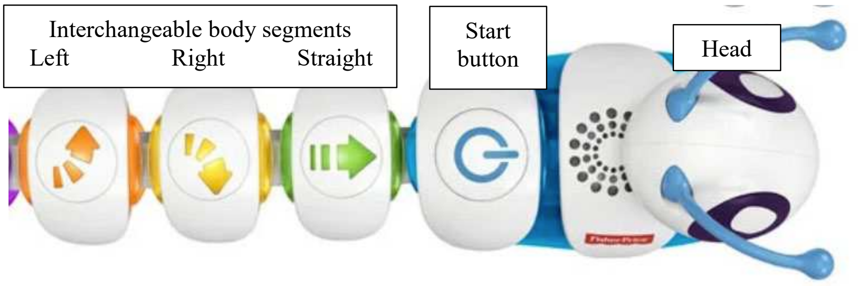


Figure 1. Code-a-pillar (named "Rapunzel" by the children in the present study)

We selected the case we present here because it illustrates how ego syntonicity and body syntonicity can be tightly interwoven as part of children's computational thinking. The session of interest occurred during the ninth week as Mr. Samuel worked with three children, David, Ned, and Peter (all names are pseudonyms) (see a screenshot of the video recorded session in Figure 2). David (aged 4) was Korean-American and an English language learner, Peter (aged 3) and Ned (aged 4) were Caucasians. Mr. Samuel, African American, had been teaching at the pre-school for 7 years.

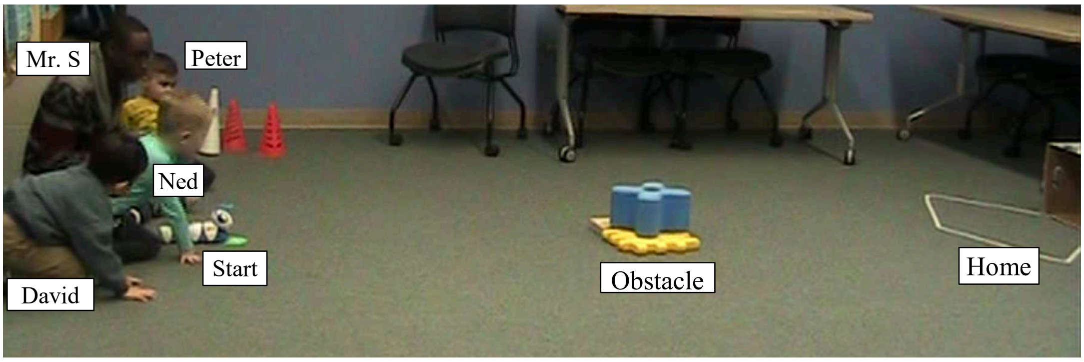


Figure 2. Mr. Samuel and the children in the focal session

Our analysis highlights how Ned's description of the route became more sophisticated over the episode, and the role that body and ego syntonicity played in this process. To understand the progression of Ned's idea about the route Rapunzel should take, we conducted a multimodal analysis of the group's interactions (Jordan & Henderson, 1995; Streeck et al., 2011) during the session. We transcribed participants' speech, facial expressions, vocalizations (e.g., response cries), body movements, and gestures. We also treated Rapunzel as a participant, and her actions were also transcribed. Our close attention to detail revealed the refinement in Ned's understanding of the Code-a-pillar's steps before and after a collaborative narration of its route. Our careful analysis of intense displays of emotional involvement during the collaborative narration revealed how these displays punctuated the Code-a-Pillar's trajectory in space to make it perceivable as a discrete sequence of steps (a form of decomposition).

Findings and discussion

During the session of interest, Mr. Samuel presented the children with a new task: Help Rapunzel, the Code-a-pillar, navigate around an obstacle (a pile of foam objects that the children imaginatively decided to be a snow mountain with a popular cartoon villain on top) and reach her home (the decorated cardboard box) on the other side of the room, about six feet away (see Figure 2). Solving the problem of getting Rapunzel from "Start" to "Home" around the obstacle required the children to break a relatively complicated continuous spatial route down into a sequence of discreet programmable steps using the commands they had available: body segments that make the Code-a-pillar (1) turn right, (2) turn left, or (3) go straight.

To program this route, the children must make sense of and comprehend (1) the continuous trajectory through space (the path or route) that will achieve the goal of getting Rapunzel from Start to Home and (2) how to organize and translate this path into a language the Code-a-pillar understands: a sequential series of commands (turn left, turn right, go straight) dictated by the segments that must be attached to her body. Translating the spatial route into a sequence of steps requires engaging in the important CT practice of *decomposition*. In addition, the children also need to engage in *debugging* to identify and rectify errors in the series of commands they choose (another important CT practice). There are two viable options: passing to the left of the obstacle or passing to the right. If passing to the left, the series of steps could be (a) straight, (b) left turn, (c) right turn, (d) straight, (e) straight, (f) right turn. This is the solution that the group eventually settled on.

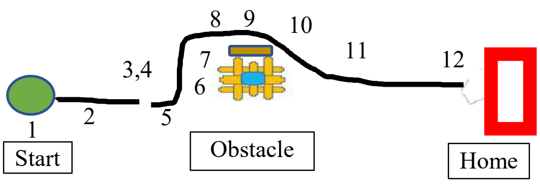
In their first attempt, the children only attached two movement segments (one straight and one left turn) to Rapunzel, and as a result, Rapunzel stopped in front of the obstacle as shown in the screenshot (Figure 4). After this failed trial, Mr. Samuel asked them to stop and think.

In response, Ned mapped out a proposed trajectory and series of steps for Rapunzel (Figure 3). Using his finger on the floor to trace a route, Ned crawled from Start to Finish around the obstacle to the left. As he traced and crawled, he named the series of commands he thought would achieve this route (see Table 1)—straight (02), straight (04), left turn (05), right turn (08), and straight (12). The screenshot in Figure 4 captures the next-to-the last step (line 12) when he almost reached Home and the diagram in Figure 3 shows where each of his speech/action lines occurred as he mapped out the route.

By physically enacting (both moving the finger on the floor and crawling forward) Rapunzel's route, Ned was using his body to both plan the path and break the path down into steps. Interestingly, although his audience was at Start, Ned faced Home and crawled with his back toward them the whole time as if he was moving as Rapunzel would. He both simultaneously adopted a *character view point* with his body (facing the direction Rapunzel faced, moving through the space as if he was Rapunzel) and an *observer view point* (using just his finger to trace the route Rapunzel would take). Crowder (1996) has demonstrated that when students adopt a character view point to use their bodies to represent ideas, they are often still in the process of making sense of scientific explanations, and when they adopt observer view-points (such as pointing), they are often relaying already thought-through responses. Here, we argue Ned's blended view point suggests he was both (1) using his body to think through the route, a form of body syntonicity, while (2) simultaneously attempting to illustrate this route for the others by using his finger.

Table 1: Ned plans out Rapunzel's route on the floor

	Ned's Speech	Ned's Action/Gesture
01	I think, we have to go	
02	straaaight, ((pause))	((Drags right finger forward across the floor toward the obstacle as he crawls forward.))
03	and then	((Pauses))
04	straaaight, ((pause))	((Sweeps finger and entire arm backward. Pauses))
05	turn. ((pause))	((Sweeps right finger forward across the floor toward the obstacle as he crawls forward.))
06	And then ((pause))	((Drags right finger slowly to the left. Pauses, then draws a left turning path .))
07	then ((pause))	((Slight pause. Traces finger on floor to go straight forward.))
08	It turns	((Traces to the right toward the home box while crawling forward))
09	This way	((Continues forward tracing a straight line with his finger as he crawls.))
10	and	((Veers to the right with his finger, around the obstacle.))
11	then	((Readjusts, moves his finger and body path straight))
12	straight	((Continues across the floor tracing a straight path into the home box.))



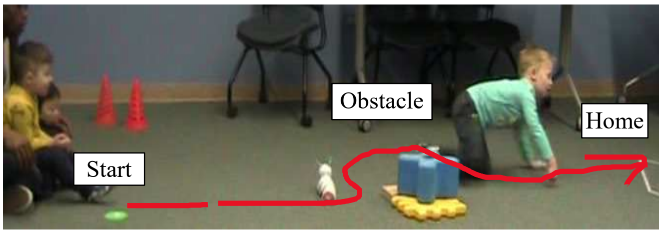


Figure 3. Diagram of Ned's route for Rapunzel

Figure 4. Screenshot of Ned planing Rapunzel's route

Although the path Ned embodied and traced could achieve the goal, he had not fully decomposed it into programmable steps that would work, particularly towards the end of the path. He would need a second right turn to properly line Rapunzel up with her "Home" (although he does embody the continuous curve of the path to get her there) and he also was missing an additional straight command to get her far enough to make it all the way home (although again he traced it). His proposed programming steps would result in Rapunzel ending up short about 2-3 feet and too far to the left of the goal.

Based on Ned's proposed route and steps, the group programmed Rapunzel by attaching five movement segments (a. straight, b. left, c. right, d. straight, e. straight). But Rapunzel stopped short to the left outside of her home. Mr. Samuel took another student, Peter, by the hand, and together they found the solution by walking the final step for Rapunzel. As a result, the group decided that they needed one last piece (f. right turn). A third student, David, attached the final piece and pressed "start."

Together, the Mr. Samuel and the group of children observed Rapunzel's "run" to see what would happen with this new revision. However, the group did not just passively watch Rapunzel progress, instead engaged in an emotionally charged collaborative narration of each step along the way. The diagram in Figure 5 shows how participants' vocalization and action lines (01-22) correspond to Rapunzel's movement (a-f) and Table 2 also uses alternative background colors (red and blue) to correspond to the color of Rapunzel route in the diagram.

Table 2: The group observes Rapunzel's home run

	Participants' Speech and Vocalization	Participants' Action	Rapunzel's Movement
01	Mr. S: Maybe some popcorn she'll have	((Children giggle))	Rapunzel starts moving forward (a)
02	when she gets home. I don't [know.		
03	Children: [OOHhhhh]	((Children lean forward))	Rapunzel continues forward (a)
04	Mr. S: Now, okaaay, now	((N puts hands over mouth))	Rapunzel begins left turn (b)
05	Mr. S: she turnnns		Rapunzel continues turning left (b)
06	Mr. S: Peter, watch, look	((Mr. S points at Rapunzel))	Rapunzel begins turning right (c)
07	Mr. S: And then a riiight turn[nnnnn]		Rapunzel continues turning right (c)
08	D&P&N: [nnnnn]		
09	Mr. S: And then a ST[raaaaaight]		Rapunzel straightens out (d)
10	D&P&N: [Straaaight]		Rapunzel moves forward (d)
11	D: anoder stre[eeeeeee]		
12	Mr. S: And then another stra[aaaight]	((N puts his hands on his mouth and sits up))	Rapunzel starts the next forward command (e)
13	D: [aaNAAHaha!	((D crawls forward))	
14	N: [Nnnnnnnnnn	((N sits further up on knees))	Rapunzel continues straight (e)
15	Mr. S: And THEN	((N inches forward))	
16	(pause)		
17	P: Mmmm[mmmmmmmmmmm		Rapunzel finishes the forward (e)
18	D: [RAAAAIGHTT]		
19	Mr. S: [AND THEN A T]URRN Aaaaaaaah]		Rapunzel begins to turn right (f)
20	Children: [mmmmmmmmmmmmmmmmmm]		Rapunzel enters the target zone, continuing to turn right (f)
21		((Mr. S throws his arms in the air and then starts clapping))	Rapunzel stops
22	D: Yeah!	((Mr. S, D, P, and N clap, and children start to dance))	

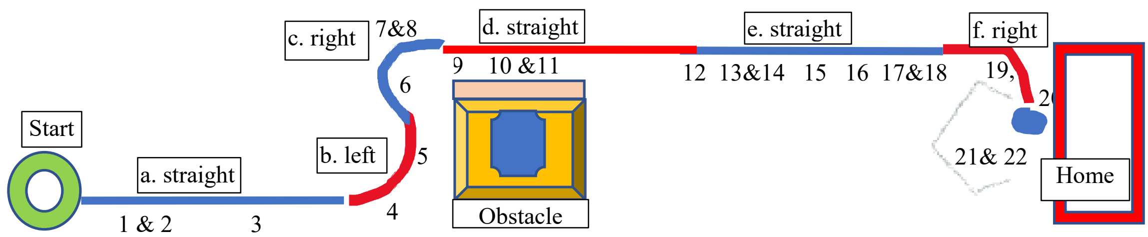


Figure 5. Diagram of Rapunzel's home run

As the run occurred, Mr. Samuel acted like a sports announcer by setting up the scene (01) and detailing Rapunzel's each step (05, 07, 09, 12, 19). The children were intensely engaged and their actions showed intense focus: leaning or inching forward (03, 15), sitting up straight (12, 14), and crawling forward (13), and holding back vocalization by covering their mouth (04, 12) at each consequential step. In addition, the group's collective response cries were precisely coordinated to respond to Rapunzel's movement. Along the way, they gasped, laughed, used elongated sounds, and engaged in playful screams and shrieks. For example, for Rapunzel's fifth movement (e. straight), the children started with intense focus (Ned sitting up with hands covering his moth in 12 and David crawling forward in 13) and cried out in excited anticipation (David uttering intensely excited noises, nearly screaming, in 13). As Rapunzel continued going straight, the children audibly lowered the volume of their response cries, e.g., Ned sat further straight and uttered "Nnnnnn" displaying nervousness (14). Finally, when Rapunzel completed this turn (e. straight), children let out louder joyful shrieks to release the tension until her next new turn started again. To coordinate their collective response cries with Rapunzel's movements and Mr. Samuel's narration, the children had to attune their attention to each place where Rapunzel's continuous spatial trajectory was broken down into the discrete steps they had programmed for her. The range of strong emotions that they performed together showed that they were deeply invested in Rapunzel's success. Overall, the children's intense embodied emotional involvement with the toy's route and programmed steps constitutes a form of ego syntonicity that appears to help them recognize how the continuous spatial trajectory was decomposed into discrete steps.

After this final run, and the body syntonicity (Table 1) and ego syntonicity (Table 2) experiences discussed above, Ned demonstrated a more sophisticated understanding of the decomposition of the route by accurately describing the steps needed to bring Rapunzel to her home (see Table 3). Ned's answer now contained the missing steps he omitted before (e, and f) as he successfully decomposed the whole route into programmable steps. Instead of describing the path through space (which was part of his first explanation in Table 1), he now only seemed to be recounting a list of the discrete programming steps. Each statement corresponded to Rapunzel's segmented movements. There were also less pauses and disfluencies (Crowder, 1996) in his recount compared to his initial planning, and he was more fluent as he described the entire route, suggesting that he was no longer thinking it through how to map the continuous trajectory to the steps, but could just see it as a list of steps. In addition, Ned's gestures were no-longer in character view point (he was only using his hand, and not his whole body), which also suggests he had made sense of the route, and was narrating what he already understood (Crowder, 1996). This is a stark contrast to the first attempt at decomposition, when he was working out the turns, as he went, with his body. Further evidence of Ned's improved competency in regards to decomposition is illustrated by the absence of gesture toward the end of his explanation. Ned did not completely gesture the last two-three steps and relied more on speech to complete the idea.

<u>Table 3: Ned recounts Rapunzel's route</u>

	Ned's Speech	Ned's Gesture
01	We had ta straight	((Moves right arm straight out, pointing finger straight.))
02	turn	((Moves right arm toward his left.))
03		((Makes a slight point forward.))
04	turn	((Extends arm back to the right and forward.))
05	straight	((Retracts arm closer to body.))
06	straight	((Slightly moves finger.))
07	and then- and then- turn.	((Moves finger slightly three times.))

01 & 02	03	04	05	07
				

Throughout Ned's participation, character view point and gestures served as an important stepping stone to developing a more sophisticated computational way of analyzing a situation, and they eventually give way into a more sophisticated description of the decomposition in words. This aligns well others' findings in math and science that that gestures can help reify and objectify abstract patterns (e.g., Radford, 2003) and play an important role in developing technical language (e.g., Roth & Lawless, 2002). However, we argue that Ned's experience is irreducible to just physical bodily activity (in this case body syntonicity). Instead, our study shows the equally important role of intense emotional engagement in learning (ego syntonicity). Collective response cries drew the children's attention to the relationship between the spatial trajectory and discrete programmable steps, and thus likely deepened Ned's understanding of the decomposition in this case.

Conclusion

As an exploratory study, we used a small group of preschoolers' embodied CT learning to illustrate how body syntonicity (BS) and ego syntonicity (ES) can both support children's' sense making of the CT practice of decomposition. While the connection between Ned's BS experience and his learning of these CT concepts and practices is well supported by other embodiment research (e.g., Crowder, 1996; Radford, 2003; Roth & Lawless, 2002), our study highlights the equally important role of ES in children's learning. Although we only focus on the role that intense emotional engagement plays (ES at a moment-to-moment micro level) through the focal session in the findings, we have noted myriads ways the children's ES are being supported. For example, the Code-a-pillar design (life-like features and actions), the curriculum design (naming Rapunzel in the introductory session – see Methods for detail), the teacher's guidance (designing tasks related to Rapunzel's needs), and children's collaboration all contributed to ES at a broader level. Overall, we argue that leaving out ES would result in an incomplete picture of Ned's embodied sense making of the decomposition of the route. Like Papert, we argue that the emotional body and the physical body both play a key role in learning to program. Therefore, we strongly advocate learning sciences communities to pay attention to both BS and ES in their examination of learning processes as well as their design of learning experiences and tools. In practice, teachers and caregivers should consider allowing and supporting children to leverage their knowledge of their body, their sense of self, and their emotions in making sense of CT concepts and practices.

By revisiting *both* of Papert's classic notions of the embodied dimensions of programming – body and ego syntonicity – and bringing them to bear in the case of young children's experiences with a new, tangible programming toy, we embody this year's conference theme by reflecting the past and embracing the future. In particular, our findings lend additional support to Papert's assertions that ego syntonicity plays an important role in how children make sense of tangible programming toys, and warrants further investigation and attention in the design of future learning experience as well as tangible programming toys for young children.

Moving forward, we are planning to extend this research in several directions. First, we will investigate the role body and ego syntonicity plays in supporting students' engagement in other aspects of CT learning. Our data already hinted at some potential effects of ES on debugging, another key CT practice. We also believe ES is particularly well suited to foster desired CT attitudes and perspectives (e.g., collaboration and communication, perseverance, productive failures, tinkering spirit) because its explicitly connects to one's sense of self. Second, we plan to further unpack the social dimensions (e.g., peer collaboration, and teacher scaffolding) of integrating BS and ES to better understand how "'making sense' is a social process" (Bruner & Haste, 1987, p. 1). Third, we will examine the affordances and constraints of tangible programming toys such as Code-a-pillar for young children's BS/ES in their sense making of CT. For example, we have noticed that Code-a-pillar's life-like features lend themselves well for children to project and to align with their own desires, needs and emotions. Code-a-pillar's interchangeable body segments can be attached and detached, which also provides an intuitive way to decompose a continuous route into discrete steps. Finally, we will also explore potential connections between the moment-to-moment emotional and embodied experiences in CT learning (i.e. BS and ES at a micro-level) and the broader macroscale processes of developing learner identities related to computer science (BS and ES at a meso or macro level). Challenging the Cartesian dualism of emotion (body) and knowledge (mind), we believe this integrated BS/ES-based approach to understanding and supporting CT learning may be especially valuable for helping make CT more inclusive for children from non-dominant communities with non-Western epistemologies.

Endnote: Transcript conventions

(1) Brackets [] show overlapping speech or vocalization that occurs at the same time.
(2) ((Double parentheses)) denote nonverbal activities and embodied actions such as gesture.
(3) CAPITALS denote loud speech.
(4) Nnnnnnnnnn extended letters show elongated sounds and cries.

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