THE ROLE OF EMBODIMENT IN COMPUTATIONAL THINKING ACTIVITIES: HOW EMBODIMENT CAN SUPPORT THE UNDERSTANDING OF ALGORITHMS IN THE CONTEXT OF PROGRAMMING EDUCATIONAL ROBOTS

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As a core competency of the 21st century, promoting computational thinking (CT) is necessary, and should begin at a young age. However, since this is an abstract concept, it is often difficult for children to grasp. Embodiment can help children acquire CT skills, especially in the early stages. As part of a qualitative study, 24 elementary school students were asked to complete a task involving decoding an arrow card algorithm for the Blue-Bot learning robot. This paper presents a particularly interesting case that covers many different approaches. It found that embodiment seems to support the CT skill of algorithmicising. In particular, visualising the position and orientation of the robot after each arrow card in the grid with the index finger appears to be promising.

INTRODUCTION

CT is an important skill for the 21st century (Wing, 2017). There is growing interest in fostering CT, especially in elementary schools, as promoting it at a young age can lay the foundation for future learning (Kwon et al., 2022). However, learning abstract activities such as CT can be challenging for children, as their abstraction skills are not yet fully developed (Statter & Armoni, 2020). Embodied learning can support acquisition of such abstract activities, especially at the beginning (Kwon et al., 2022). Hence, this study will take a look at the role of embodiment performing CT activities.

IMPROVEMENT OF CT THROUGH THE BLUE-BOT

Among numerous definitions of CT, this paper follows Wing's definition (2017, p. 8):

> Computational thinking is the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer – human or machine – can effectively carry out.

One way to promote CT is using educational robots. Hong (2023) demonstrates that the most significant effect of promoting CT with robots occurs in the early school years, which makes promotion in elementary school particularly relevant. One example of a learning robot suitable for elementary schools is the Blue-Bot. This robot was used in a study by Büscher (2025), which examines the CT activity of algorithmicising (planning a step-by-step approach). Children were asked to program the Blue-Bot along a path with the help of an algorithm represented by arrow cards (Figure 1). Büscher detects that this involves an interplay between encoding and decoding. The

2026. In H. Krzywacki, M. Hähkiöniemi, E. Haataja, M.S. Hannula & P. Hästö (Eds.). *Proceedings of the 49th Conference of the International Group for the Psychology of Mathematics Education: Research Reports*, pp. 595-602. PME.

learners laid out the cards indicating the path the robot should follow (*encoding*), but also repeatedly translated the laid-out cards into robot movements (*decoding*). This enables them to understand which field the robot is on and in which direction it is facing at each card, so that they can continue planning from the corresponding point in terms of encoding. Büscher notices that the learners use gestures that seems to support the process of encoding and decoding. She hypothesises that this could be due to the "embodied nature of mathematics learning" (Büscher, 2025, p. 7) but does not investigate this. This paper aims to analyse the connection between gestures and the CT-activity of algorithmicising.

THE ROLE OF EMBODIMENT IN CT WHILE PROGRAMMING ROBOTS

The relevance of gestures and embodiment in general becomes clear when taking a closer look at the process of thinking. According to Radfort (2008, p. 111), "thinking does not occur solely in the head but also in and through a sophisticated semiotic coordination of speech, body, gestures, symbols and tools". Physical actions and gestures are an integral and supportive part of mathematical cognition. They make mathematics tangible (Radfort, 2008).

In task designs, embodiment can be integrated into the task to varying degrees. According to Skulmowski and Rey (2018), it is possible that embodiment is explicitly addressed in the task (*integrated*) or that it is only triggered incidentally by the learners, possibly due to key terms (*incidental*). Furthermore, they distinguish between two forms of physical activity: Actions that can be performed while sitting (*low level embodiment*) or actions that require the use of the whole body (*high level embodiment*).

Studies show that embodied learning experiences can help elementary school students understand abstract CT concepts (Kwon et al., 2022). Activities with robots that are physical in nature offer learners the opportunity to use various tools (e.g., the robot itself) to connect their abstract thinking with their environment. A study by Kopcha and Ocak (2019), in which learners were asked to program a learning robot across a 3x3 grid, shows that the learners often use embodiment. They especially use gestures that mirrored basic robot movements to solve problems. According to Kopcha and Ocak (2019), this helps the learners to take the robot's perspective, what is particularly important when debugging the solution and reprogramming the robot's movement. The extent to which embodiment also supports other CT activities is not described in detail. A study by Kwon et al. (2022) also indicates that embodied activities can improve not only spatial thinking, but also CT skills when programming a robot.

Based on previous research, it can be concluded that embodiment plays an important role in CT, particularly in programming learning robots. However, it remains unclear how exactly physical actions can support CT. This raises the following question:

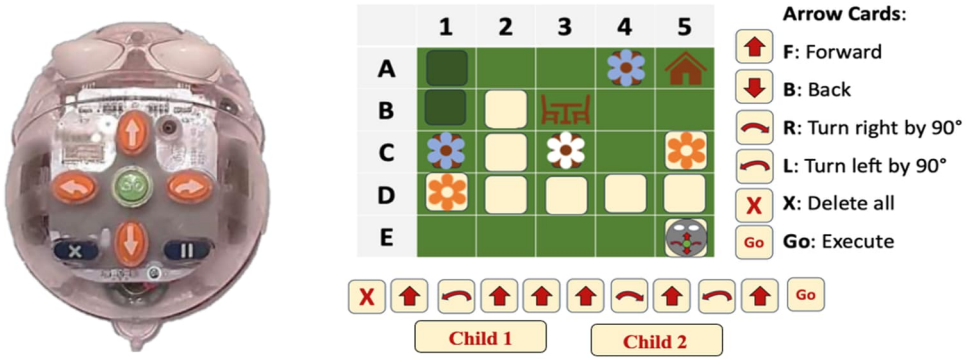
RQ: *What forms of embodiment are involved in decoding an arrow card algorithm, and how do these actions influence the CT activity of algorithmicising?*

METHODS AND DESIGN

A total of 24 learners between the ages of 6 and 10 who had no previous experience with CT or programming robots at school participated in the study. The learners worked in pairs on tasks with the Blue-Bot. Video data was captured and fully transcribed, and the CT activities were reconstructed. From the data, a particularly interesting case was identified: The six-year-old learner Lena needs several attempts to correctly determine the target field and uses many different approaches. Some of them are more promising than others. Hence, we analysed Lena's case in more detail with regard to the gestures that occurs. Since Lena is initially unsuccessful but later become more successful with a different approach, it is possible to make initial assumptions about which embodied actions seem to support programming the robot and which do less. The use of a single case enabled an in-depth and detailed analysis of the physical actions Lena uses to program the robot. For the analysis, we inductively categorised Lena's physical actions using Qualitative Content Analysis (Kuckartz, 2019). We qualitatively interpreted how these gestures might influence the process, particularly with regard to *decoding*.

In the task, the children were asked to determine which target field the robot would reach, starting at E5 and facing D5, if it follows the program consisting of arrow cards in front of them: X, F, L, F, F, F, R, F, L, F, Go (Figure 1). Since the fields of the grid were not labelled in the actual study, the children were encouraged to use pointing gestures to identify the robot's position. Nevertheless, the structure provided by the grid can be helpful, as demonstrated in a study with Blue-Bots by Ferrara (2025). To determine the target field, it is necessary for the children to decode the program.

Figure 1: Blue-Bot and setting (based on Büscher, 2025)



EMPIRICAL RESULTS OF THE CASE STUDY

The case of Lena illustrates how children can approach decoding a program. In the following presentation of the analysis, the focus is placed on the use of embodiment in accordance with the research question. The following transcript excerpts are literally translated from German. All statements not relevant to the analysis, especially those made by the other child, are omitted. In the excerpts, the first turn number is stated if there was a change of speaker in the meantime that is not printed.

First try: Rarely using the whole body – Partially demonstrating the orientation

290 I: So please first decide together where you arrive. Then tell me, and then you can ride with the robot. […]

294 Len: X. Straight ahead. […] After [Len turns her upper body slightly to the left] left. # […] Then we [Len lifts her upper body, which is turned slightly to the left, two or three times and returns to her starting position]. […] # back again.

302 I: And where did he land?

303 Len: Flower here. [Len points her right index finger toward the flower in C5]. […] Back. […]

307 I: Did he land in exactly the same place again?

308 Len: Or here [Len points to D5 with her right index finger].

When Lena was given the general task of determining where the Blue-Bot would land (#290), she uses just little embodiment. She only turns her upper body slightly to the left during the first left turn and lifts her upper body slightly in accordance with the following forward movements (#294). Since Lena also only verbalises the first three arrow cards (#294), she might be only guessing the target field, as the interviewer later suspects (#309), instead of decoding the entire program. This could explain why she probably considers two different incorrect target fields (#303/308).

Second and third tries: Using hand gestures over the arrow cards – Pointing at the currant arrow card and partially demonstrating the direction of rotation

309 I: Please think about it with the cards, don't just guess.

310 Len: [Len points with her right index finger to the cards one after the other: to the 1st card (X); to the 2nd card (F); ...] He has already gone.

[... to the 3rd card (LD), turning her hand slightly to the left; ...] Then he turns around ...

Straight ahead [... to the 4th card (F), leaving her hand slightly turned to the left; to the 5th card (F), leaving her hand slightly turned to the left; ...], straight ahead [... to the 6th card (F), leaving her hand slightly turned to the left; ...],

turn around [... to the 7th card (R), turning her hand to the right; the finger changes its orientation by approx. 180°; ...]. He has landed back there.

Straight ahead [... to the 8th card (F), leaving her hand slightly turned to the right; ...],

turn around [... to the 9th card (L), turning her hand to the left; the finger changes its orientation by approx. 90°, so that the finger is "straight" as it was at the beginning; ...],

straight ahead [... to the 10th card (F); ...],

and go [... to the 11th card (Go), her hand appearing to be turned slightly to the right again; Len points briefly at D2 several times with her right index finger].

After the interviewer instructs Lena to use the cards (#309), she points her index finger at each arrow card in turn and slightly changes the orientation of her finger on the rotating arrows, even though at no point does she visibly hold her finger as if indicating a direction. Meanwhile, she translates the corresponding arrow cards into language, except from the middle one of the three straight arrows. Based on her interjections “He has already gone.” or “He has landed back there.” (#310), it seems like Lena is thinking about where the robot is in relation to the arrow cards on the grid, even though it is not physically visible. Here, too, she ends up naming a wrong target field.

313 I: Please explain that to me with the cards.

314 Len: I already have ... looked.

315 I: Can you explain that to me again briefly? ... So, on dele #

316 Len: # on X [Len points her right index finger to the first card (X)], straight ahead [Len points her right index finger to the second card (F); Len holds her right index finger over the third card (L) so that it points to the left] #

At the renewed request to explain using the cards (#313), Lena begins pointing at the cards again. This time she visualises the orientation of the left turn even more clearly by stretching her finger visibly to the left above the first L-card (#316). Lena seems to consider translating the cards into language and pointing at them as an explanation with the cards, because she stresses that she has already explained this with the cards (#314).

Fourth try: Using hand gestures over the grid – Demonstrating the position and partially the orientation

Afterwards, the interviewer interrupts her and emphasises for the first time that Lena should not only translate the cards into speech but also indicate where the robot is standing according to the cards. Since the interviewer is pointing toward the grid, she could be trying to suggest that Lena should use this for illustration (#317).

317 I: # Wait, wait, wait. [Len puts her hand back on her lap] Don’t just read what’s written there. Straight ahead [Leh points her index finger from a distance toward the cards, presumably toward the second card (F)], where is it then [Leh points her index finger from a distance toward the grid]? The robot? If it goes straight ahead.

318 Len: [Len points her right index finger to D5]

319 I: Okay, and now he turns once to the left.

320 Len: [Len briefly points her right index finger to the third card (L), while her finger is slightly turned to the left] Left [Len points the same index finger to D4, while her finger is turned to the left].

321 I: Where is he looking? [Len puts her hand back on her lap] Is he looking over there [Leh points to the left]?

322 Len: Yes.

323 I: And then he walks straight ahead three times. Where is he then?

324 Len: Yes. Here [Len points with her right index finger to D2].

325 I: Mhm. [Len puts her hand back on her lap] And then?

326 Len: And then it turns around again [Len points her right index finger at D2 again, while her finger points to the right, which would imply a 180° turn]. No, like this [Len turns her index finger in D2 90° to the left so that it points in the direction the BB would actually be looking].

327 I: So, once to the right, exactly.

328 Len: And then he goes straight ahead [Len moves her index finger to C2, still pointing in the same direction as before]. And then he turns around [Len turns her index finger 90° to the left in C2]. Then he goes straight ahead [Len moves her index finger to C1, still pointing in the same direction as before] # […] And then go. Ah, she lands here [Len points her left index finger to C1].

Following these specific instructions, Lena uses the grid for visualisation for the first time. Under the guidance of the interviewer, Lena points her index finger to the fields on the grid where the Blue-Bot would be located. When asked about his position after the first straight movement (#317), Lena correctly points to D5 with her index finger (#318). After the interviewer verbalises the meaning of the next arrow card (#319), Lena briefly points to the corresponding L-card, holding her finger slightly to the left, similar to her approach in the second attempt. She then points her finger to the left in D4 in accordance with the orientation of the Blue-Bot (#320). During this turn, she seems to have moved one square too far. However, when questioned about the location of the Blue-Bot after the three subsequent straight steps (#323), Lena correctly points to D2 (#324). Either she accidentally took only two steps straight ahead instead of three, and this mistake compensates for the previous one, or she already visualised the first of the three steps straight ahead when she pointed earlier. After that, the interviewer's question "And then?" (#325) seems to be enough for Lena to finish planning the route by pointing to the grid. While doing so, she always visualises not only the position but also the orientation of the Blue-Bot by pointing her index finger in the corresponding direction. At the same time, Lena verbalises the meaning of the cards or the associated actions of the Blue-Bot (#326/328). When visualising the orientation of the Blue-Bot on the grid, Lena corrects the error that when turning right, the Blue-Bot does not turn to the right as seen from her perspective, which is in the direction the arrow is pointing, but instead turns 90° further to the right from its previous position (#326). Proceeding in this way, Lena determines the correct target field for the first time (#328).

DISCUSSION AND CONCLUSION

Similarly to the studies by Kopcha and Ocak (2019) and Kwon et al. (2022), embodiment seems to improve CT skills. It seems to play a central role in algorithmicising and especially in decoding. However, the form of embodiment appears to be crucial for success. Table 1 summarises the forms of embodiment that Lena uses when decoding. However, Lena sometimes uses mixed forms. For example, she does not always use the grid but also points to suitable arrow cards.

Table 1: Forms of embodiment while decoding used by Lena

Form of embodiment	Used body parts	Used material	Form of visualising
without			
high level	whole body		orientation
			number of steps
low Level	hand gestures, especially the index finger	arrow cards	current arrow card
			direction of turning
		grid	position
			position and orientation

Similarly to Radfort (2008), this study shows the connection between embodiment and language. Lena often verbalises the arrow cards while decoding, but this only became successful in combination with embodiment. Thus, the approach of pointing to the corresponding field on the grid (*low-level embodiment*) while translating each arrow card or each group of same arrow cards seems to be the most promising approach. Especially, if the orientation of the robot is also indicated. This shows that, as in Ferrara's study (2025), the grid plays a central role in structuring. Pointing to the arrow cards in between this approach does not seem to confuse (cf. first L-card in the fourth attempt, #320), but it does not seem to be necessary for decoding (cf. other cards in the fourth attempt). It cannot be determined if it is sufficient to visualise the position of the Blue-Bot only after the same consecutive arrow cards. In the only case where Lena visualises the position after several same arrow cards (three F-cards, #324), it is possible that she reaches the correct target field only because of a previous mistake.

Lena's case highlights the importance of giving precise instructions and providing children with more guidance at the beginning if they have problems to reach the target field. It seems useful for the children to give instructions on meaningful intermediate information (position and orientation of the Blue-Bot after each (group of same) arrow card(s)). With reference to Skulmowski and Rey (2018), in Lena's case this results in the incidental use of embodiment even though it is not integrated into the task. However, it remains open if Lena will be able to use this approach in the future without guidance. Other pairs also successfully use Lena's final approach. Some of them even manage it with less assistance. Pairs that use few or other embodiment approaches usually have greater difficulty determining the target field. However, it remains unclear if the initial use of physical actions can enable children to later decode exclusively in their minds without mistakes, for example by imagining pointing gestures. Accordingly, a follow-up study is appropriate in which children should be first guided

by the interviewer, similarly to Lena, but probably also with embodiment approaches integrated into the task. Afterwards, children could be asked to try it on their own and finally to proceed exclusively in their mind. This can be accompanied by verbal descriptions for better comprehensibility. Additionally, it remains unclear if embodiments can help in a similar way with other CT activities because the analysed task is focusing on decoding. To clarify this, other task formats need to be examined.

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