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Moving towards understanding graphical representations of motion

Carolien Duijzer[1], Marja Van den Heuvel-Panhuizen[1 2 3], Michiel Veldhuis[1 4] and Michiel Doorman[2]

[1]Freudenthal Group, Utrecht University, Faculty of Social and Behavioural Sciences, the Netherlands; a.c.g.duijzer@uu.nl; m.veldhuis@uu.nl

[2]Freudenthal Institute, Utrecht University, Faculty of Science, the Netherlands; m.doorman@uu.nl

[3]Nord University, Norway; m.vandenheuvel-panhuizen@uu.nl

[4] iPabo University of Applied Sciences, Amsterdam, the Netherlands

Making connections between variables and proficiently constructing graphical representations is key to higher-order thinking activities within mathematics and science education. In our research, we make use of a learning environment informed by embodied cognition theory to promote students' graphical understanding. In the teaching sequence offered to fifth graders, students created distance-time graphs describing their own movements in front of a motion sensor. In a pretest-intervention-posttest design, we investigated whether task-related bodily movements enhanced students' understanding of graphs of motion, as reflected in their competence in interpreting and constructing graphs. Preliminary results point to important links between students' motion experiences and their ability to reason about the relationship between distance and time as represented in graphs.

Keywords: Graphs, primary mathematics education, embodied cognition, motion, modelling.

Introduction

Students' difficulties with understanding graphs is a much-studied topic. Such difficulties become especially apparent when graphs include a time-dependent variable, as for example in distance-time or speed-time graphs. Then, students can be prone to focus on surface characteristics of the graphs, such as the slope and interpreting it as an indication of moving up or the height and viewing it as an indication of highest point (e.g., Glazer, 2011). However, good understanding requires that students discover the deeper connections underlying the represented data and start to think about the relationship between multiple variables and "their pattern of covariation" (e.g., Leinhardt Zaslavsky, & Stein, 1990, p. 11). According to Friel et al. (2001) students have to develop *graph sense*, which "develops gradually as a result of one's creating graphs and using already designed graphs in a variety of problem contexts that require making sense of data" (Friel, Curcio, & Bright, 2001, p. 145)".

Developing graph sense can be seen as higher-order thinking. It implies reasoning about graphs, including interpreting, constructing, changing, combining, and comparing graphs (e.g., Boote, 2014). In order to foster students' understanding of graphs and related reasoning, we designed a teaching sequence in which students are given ample opportunities to experience firsthand how their own bodily movements are represented as a graph. The idea that bodily experiences can be beneficial for learning, is captured within the theory of embodied cognition.

Theoretical background

Embodied cognition theory states that when we interact with our physical environment valuable perceptual-motor experiences are acquired through which our cognition is shaped. This makes our acting body one of the most important factors for learning (e.g., Wilson, 2002). According to embodied cognition theory this learning does not only include the acquisition of lower-level cognition (e.g., motor development) but it also incorporates the acquisition of higher-level cognitive processes (e.g., language and mathematics) (e.g., Barsalou, 2010). Evidence for the idea that thinking and learning are embodied has inspired researchers to incorporate bodily movements in educational environments in order to improve student learning. Often this involves activities in which students are instructed to make whole- (or part-)bodily movements, or to observe movements (e.g., Ruiter, Loyens & Paas, 2015). Whereas all these bodily experiences are considered to be embodied, some researchers argue that activities in which the whole body partakes have some additional benefits. For example, the body might become a mathematical object itself (e.g., *being a number, being the graph*) and, in a more collaborative vein, the body might become an object for collective sense-making (Kelton & Ma, 2018; Ma, 2017).

Embodied learning environments supporting students' understanding of graphing change are based on the premise that providing students with valuable bodily experiences that are immediately linked to the target concepts could alleviate students' difficulties with graphs representing change over time (e.g., distance-time graphs). In the context of modelling motion, this would imply a strong grounding of the concept of change in experienced (own) motion. For a recently carried out literature review (Duijzer, Van den Heuvel-Panhuizen, Veldhuis, Doorman, & Leseman, 2019), embodied learning environments supporting students' understanding of how to graph change were characterized on the degree of bodily involvement (own and others/objects' motion) and immediacy (immediate and non-immediate). Immediacy refers to whether a learning environment deals with on- or off-line cognitive activities. Off-line cognitive activities become grounded through embodied mechanisms such as mental simulation or imaginative activities (e.g., Barsalou, 2010). For example, when students walk in front of a motion sensor and see the graph of their own movements appear in real-time on the screen of the computer, the activity is "on-line" and the experience immediate. When students obtain this graph of their own movements at a later stage, the activity is "off-line" and hence the experience non-immediate. The review unveiled that learning environments making use of students' own movements immediately linked to their representation were most effective in terms of learning outcomes. These learning environments often made use of motion sensor technologies to immediately track a dynamic event as a line in a graph. This immediate link between one's own movement and a graphical representation of this movement was found to be an important mediating factor of these embodied learning environments.

Although over the past couple of decades much research has been published showing that one's own motion experiences might be helpful in learning motion graphs, practical applications are still scarce. Most of the research investigating the role of perceptual-motor activities on primary school students' understanding of graphical representations of motion has been done with individual students, looking at micro processes of development (e.g., Ferrara, 2014). We wanted to shift this accentuation a bit and investigate how the use of embodied learning environments translates to whole classrooms. In doing so we built on work done by others. For example, Deniz and Dulger (2012), showed positive effects of an inquiry-based instruction condition enriched with real-time graphing technology in which fourth graders were asked to replicate given motion situations. The other instruction condition used traditional laboratory equipment (i.e., a bottle of water with a hole and measuring tape). In the traditional laboratory condition students were allowed to move as well, but the immediate real-time link between motion and graph was missing. Considering these findings, it could be argued that having the opportunity to move, as well as immediately seeing your movements reflected as a graphical representation is helpful for learning about graphs of motion for students of this age. Therefore, we further explored this issue by contrasting a group of students participating in classroom activities including immediate whole-bodily movements with a group of students participating in regular classroom activities, without having the experience of moving yourself.

Current study

In this study, we investigated the effects of an intervention, comprising a teaching sequence including immediate task-related whole-bodily movements, on students' understanding of graphing change. Our research question was: *What is the effect of a classroom intervention including students' own whole-bodily movements on students' ability to interpret and construct motion graphs?* We hypothesized that an intervention in which task-relevant bodily movements were made, would result in better learning and test performance on interpreting and constructing graphs than an intervention in which students were not given this opportunity.

Method

To answer the research question, we set up a quasi-experiment in a classroom setting with a pretest-intervention-posttest design containing two experimental conditions in which students were offered a teaching sequence on graphing change in motion and a control condition in which the students did not get this teaching sequence. Instead these students received a teaching sequence (similar in intervention duration and time of intervention) on probability to take into account the effect of having an intervention on students' learning gains. The first experimental condition was embodied, meaning that the students were allowed to move around freely, while in the second experimental condition, the non-embodied one, the students did not have this opportunity. Therefore, the main difference between both conditions was the dynamicity of the movement presented to the students as well as the opportunity to physically experience the target concept of graphically represented motion.

Participants

Participants were 218 fifth-grade students (94 female, mean age = 10.29 years, *SD* = 1.46) from 9 classes of 8 Dutch elementary schools. The classes were randomly divided over three conditions: embodied experimental condition (*n* = 70), non-embodied experimental condition (*n* = 68), and control condition (*n* = 80). The research was conducted in accordance to the ethical guidelines of the Institutional Review Board of the faculty of Social and Behavioral Sciences at Utrecht University.

Procedure

The participants in the experimental conditions participated in a teaching sequence of six lessons on graphing change in motion, participants in the control condition participated in a teaching sequence of six lessons on probability. The students received the teaching sequence at different time periods throughout the year, see Figure 1. All participants took four identical macro tests at fixed time points spread over the year and six micro tests which were administered after each lesson. All lessons on graphing change were given by the same teacher, the first author of this paper.

Condition	**N** Classes (students)		**Phase 1** (October-November)		**Phase 2** (January-February)		**Phase 3** (April-May)	
1	(*n* = 21)	M1	Lesson 1-6	M2		M3		M4
	(*n* = 22)	M1		M2	Lesson 1-6	M3		M4
	(*n* = 27)	M1		M2		M3	Lesson 1-6	M4
2	(*n* = 24)	M1	Lesson 1-6	M2		M3		M4
	(*n* = 23)	M1		M2	Lesson 1-6	M3		M4
	(*n* = 21)	M1		M2		M3	Lesson 1-6	M4
3	(*n* = 25)	M1	Lesson 1-6	M2		M3		M4
	(*n* = 30)	M1		M2	Lesson 1-6	M3		M4
	(*n* = 25)	M1		M2		M3	Lesson 1-6	M4

Figure 1: Research design

Teaching sequence

The main learning objective of the teaching sequence was to foster students’ understanding of motion graphs. In the lessons we focused on graphs representing dynamic situations, where distance changes over time. The teaching sequence started with an activity in which students were asked to develop their own representation of a familiar motion event (i.e., their journey from home to school). After this, students received motion situations involving the representation of motion as discrete graphs, followed by the representation of motion as continuous graphs. Throughout the remaining part of the teaching sequence students were asked to draw graphs of given motion situations and reconstruct possible events from continuous graphs. See Figure 2 for an overview of the instructional sequence.

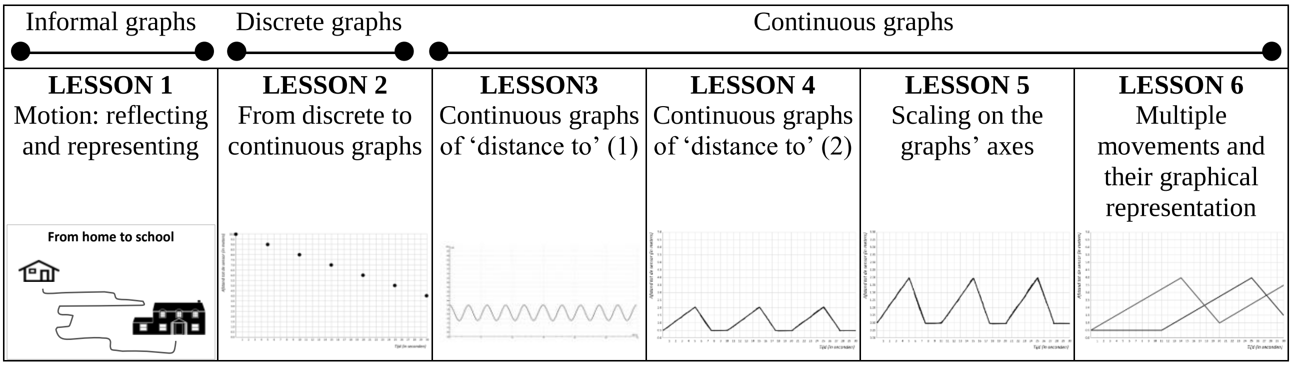


Figure 2: Overview teaching sequence

In the embodied experimental condition, the teaching sequence was enriched with students’ own motion experiences. These motion experiences varied in extent and duration over the different lessons. In the first lesson, students had to enact two slightly differing motion situations by walking along a straight line. The non-embodied experimental condition practiced this exercise differently. They received the motion situations on the digital blackboard, as well as on paper, and had to discuss these in small groups without enacting them. From the second lesson onwards, motion sensor technology was used in the embodied experimental condition. In the second and the sixth lesson the whole classroom was involved in these activities, whilst in the third till the fifth lesson students worked together in smaller groups. This gave each student the opportunity to physically experience how their movements related to the line in the graphical representation. Again, students in the non-embodied experimental condition performed the same tasks, but without enacting the movements themselves.

Motion sensor technology

In order to provide the students with an immediate link between a dynamic situation (moving in space) and its graphical representation (restricted to distance to a point over time) we included two €Motion sensors, developed by CMA, in conjunction with Coach6 Software (Heck, Kedzierska, & Ellermeijer, 2009). The tool was connected to the digital blackboard (Lesson 2 and Lesson 6) or to laptop computers (Lesson 3-5). The motion sensor was set to provide a single graph representing the distance between the sensor and the nearest object over a 30 second period. Moving backwards in front of the sensor, resulted in an increase of distance between the sensor and the student, while moving forwards resulted in a decrease of distance between the sensor and the student. To familiarize students with the motion sensor they were asked to replicate a distance-time graph of a back-and-forth movement (see Figure 3 on the left), which resulted in student created graphs (see Figure 3 on the right). In Lesson 3 till Lesson 5, students had many individual opportunities to move in front of the sensor. In Lesson 2 and Lesson 6, most students observed other students who were walking.

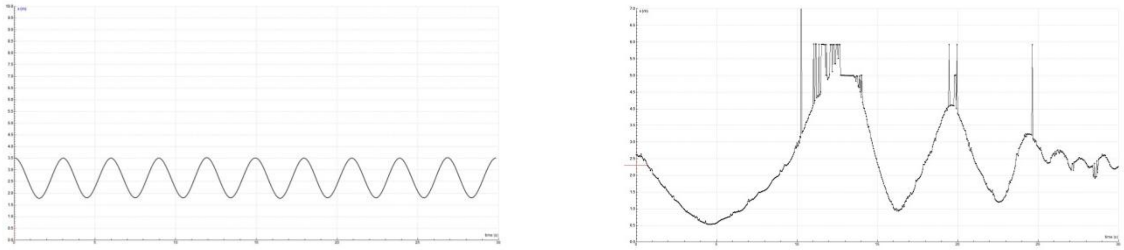


Figure 3: Given graph of a back-and-forth movement (left) and graph produced by a student in front of the motion sensor (right)

Measures

The paper-and-pencil macro test was administered to the students in order to measure their understanding of motion graphs as an indication of domain-specific mathematical higher-order thinking. Students completed five problems that assessed their knowledge of graphing. The test consisted of three graph interpretation items and two graph construction items. Two example items are shown in Figure 4. Four items could be answered correctly or incorrectly (i.e., a score of 1, 0). One item could be answered correctly, partially correctly, or incorrectly (i.e., a score of 1, 0.5, 0). This resulted in a possible maximum score of 5 and a minimum score of 0. We also coded students' answers on their level of reasoning. We included four levels of reasoning. For this paper, we only look into students' correct or incorrect answers.

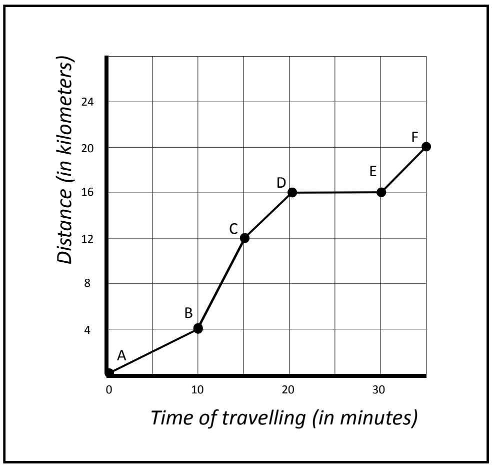
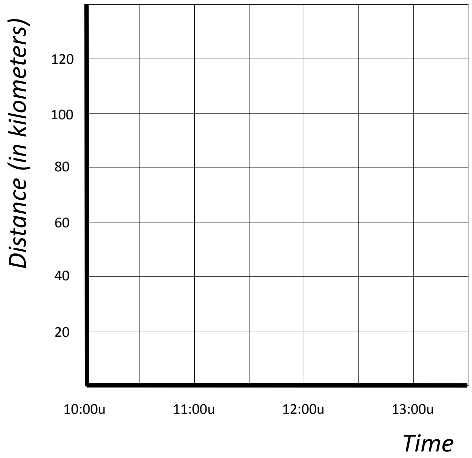
Example item 1	Example item 2
A car drives through town  1a. Between which points does the car goes fastest? 1b. How do you know? *Score: correct (**1**), incorrect (**0**)*	A train ride. A train travels **twice as fast** between **10:00 and 11:00** o'clock than between **11:00 and 12:00** o'clock. The train stands still from **12:00 to 13:00** o'clock.  2a. Draw a graph that fits the description above. 2b. How do you know? *Score: correct (**1**), incorrect (**0**)*

Figure 4: Items macro test

Analysis

A mixed 3 (condition: embodied experimental, non-embodied experimental, control) x 4 (time of testing; pre-, post, and/or follow-up) staged comparison design with repeated measures was used. For now, we will focus on the tests administered before and after taking part in the intervention, see Figure 1. Our dependent variable was students' achievement on the mathematical higher-order thinking test.

Results

In this paper we only provide the descriptive statistics of student' scores on the graphing motion test based on the correctness of the students' answers. Table 1 shows the pre- and post-test graphing motion scores for students in each of the three research conditions. On average the students in the intervention conditions increased in their understanding of motion graphs, regardless of whether they received an intervention on motion graphs. However, the embodied experimental condition showed higher gains from pre- to posttest (M_{dif} = 1.33), when compared to the non-embodied experimental condition (M_{dif} = 0.62), and the control condition (M_{dif} = 0.25).

Phase	Intervention condition	Macro test				
		Pre-test		Post-test		Gain score
		M	*SD*	*M*	*SD*	M_{dif}
1	Embodied experimental	1.21	0.94	3.20	1.15	1.99

2	Embodied experimental	2.70	1.38	3.73	1.17	1.03
3	Embodied experimental	2.65	1.60	3.70	1.37	1.05
Total		2.24	1.50	3.57	1.25	1.33
1	Non-embodied experimental	1.88	1.26	3.31	1.04	1.43
2	Non-embodied experimental	3.50	1.11	3.52	1.29	0.02
3	Non-embodied experimental	2.90	1.39	3.40	1.28	0.50
Total		2.74	1.42	3.36	1.25	0.62
1	Control condition	1.58	1.03	1.74	1.36	0.16
2	Control condition	2.50	1.51	2.70	1.41	0.20
3	Control condition	2.02	1.51	2.46	1.45	0.44
Total		2.06	1.41	2.31	1.45	0.25

Table 1: Descriptive statistics of the students' macro test scores for the three conditions

Discussion

Based on the descriptive statistics of students' scores on the macro test we found that students who participated in a six-lesson embodied teaching sequence on graphing motion showed higher gains in their understanding of motion graphs than students in the non-embodied experimental condition or in the control condition. Moreover, students' dynamic interaction with the, by motion sensor technology created, graphical representation of their own movements indicates that the embodied learning environment contributed to their understanding. In particular, this is in line with studies which have found that immediate own motion experiences are effective for learning (e.g., Duijzer et al., 2018). Moreover, our results do not only support the findings of previous research that incorporated motion sensor technology, but they also add to our knowledge of using embodied learning environments in whole classroom settings. As such, our results extend earlier findings of Deniz and Dulger (2012).

Classic theories of cognitive science assume the creation of mental structures to guide or develop mathematical understanding. Another perspective is the embodied perspective taken in the current study. According to Nemirovsky, Kelton and Rhodehamel (2013), mathematical understanding is constituted on the basis of perceptual and motor experiences. In line with this, we assume that the mathematical understanding that arose in our students was strengthened by the graphical representation of their own movements immediately created by the motion sensor. Hence, students' mathematical understanding of motion graphs became grounded in their sensorimotor experiences (i.e., continuous transformations of whole-bodily activity) that they gained when moving in front of the motion sensor, while sharing and discussing their experiences with other students.

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