DeafMath: Exploring the influence of sign language on mathematical conceptualization

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Sign languages are performed in a modality other than spoken languages, using the entire body in a spatial-visual-somatic way. With reference to spoken language, performance of the language in terms of articulation, but also perception and interpretation, changes in the medium of sign language as a visual means of expression. Considering mathematical discourse and social interaction as an important factor in the learning of mathematics, this paper discusses theoretical approaches of a research program, currently underway, that aims at getting a better understanding of how the use of sign language may influence the learning of mathematics. From this a more profound basis shall be derived for developing didactical strategies responding to the special needs of deaf learners and understanding the role of bodily language in mathematical conceptualization.

Keywords: Sign language, deaf learners, gestures, mathematical discourse and social interaction.

Introduction

Research in the area of Deaf studies and Deaf education points at the special challenges deaf students face when learning mathematics. Their lack of basic mathematical skills—deaf children lack several years on average behind hearing peers (Nunes, 2004; Traxler, 2000)—is considered to be mainly caused by social and linguistic aspects.

Deaf children do not ‘pick up’ informal knowledge (Ginsberg, Klein, & Starkey, 1998) about mathematical concepts in early childhood as easily as hearing children do, due to growing up in an environment that is primarily aligned to auditive social experience (Nunes & Moreno, 1998). For example, everyday phrases of “mathematical conversation” (Gregory, 1998) just as ‘It is five to twelve’ or ‘Turn right in three quarters of a mile’ can provide a first contact to numbers that is not accessed ‘en passant’ by deaf children. Not necessarily growing up in a deaf community, they may also lack everyday interaction with peers that may initiate first instances of problem solving in playful situations, e.g. dividing a quantity in equal parts. Furthermore, deaf learners struggle with reading, understanding and processing written word problems (Hyde, Zevenbergen, & Power, 2003). Their challenges are partly explained by a decreased short term memory in serial recall of linguistic material, by a problematic comprehension of certain language structures like conditionals, comparatives, inferentials and lengthy passages (Rudner, 1978), and by the semantic understanding of the written language as a second language (Barham & Bishop, 1991; Traxler, 2000).

Hence, and probably as no surprise, language is considered a main factor influencing the learning of mathematics for deaf learners. However, language has mostly been considered a problematic condition that impedes deaf students’ learning rather than investigated as an integral part of the learning process itself. As a spatial-visual-somatic language, the sign language used by the Deaf provides access to mathematical ideas different than that of spoken language. But what exactly does this mean for the learning of mathematics? And what can we learn from looking at how learning under these special conditions takes place?

The approach presented takes into account the specificity of sign language to encounter the peculiar characteristics of mathematical discourse and social learning processes in the deaf classroom. Furthermore, I support the claim that the modality of language not only affects how mathematics is learned, but that it also influences how mathematical ideas become conceptualized by impacting the structure and process of thinking (Healy, 2015). This contribution therefore outlines theoretical approaches and possible implications of a new research program that aims at developing a better understanding of how mathematics is learned using the medium of sign language.

Sign language(s) and gestures

Sign languages are visual languages that are formed by several components such as the configuration, movement and orientation of the hands and their location in space, body posture, facial expression and the viseme (or ‘mouthing’: the movement of the mouth). These aspects shape what is considered the utterance in sign language and are, just as spoken language, more or less conventionalized. These conventions distinguish the manual expression from the gestures defined in the style of McNeill. While he defines co-*speech* gestures as “idiosyncratic spontaneous movements of the hands and arms accompanying speech” (McNeill, 1992, p. 37), I adapt this definition for an understanding of co-sign gestures as being ‘idiosyncratic spontaneous movements of the hands and arms’ *accompanying the signed discourse.* Signers use non-conventionalized gestures in addition to the signs and both types of gestural expression can hardly be distinguished (see also Healy, Ramos, Fernandes & Botelho Peixoto, 2016). Being performed in the same visual-gestural modality, signs and gestures are deeply intertwined in their use and in their interpretation, probably even more intertwined than in the case of spoken language.[1]

Cognitive aspects of the influence of sign language on the learning of mathematics

Embodied cognition

Following the theory of *embodied cognition*, our (mathematical) thinking is deeply influenced by how we experience the world as physical beings (Lakoff & Núñez, 2000). How we act in and perceive the world structures our thinking and shapes to large extent our conceptual understanding:

> Human concepts and human language are not random or arbitrary; they are highly structured and limited, because of the limits and structure of the brain, the body, and the world. (Lakoff & Núñez, 2000, p. 1)

A slightly more cautious claim is stated by Wilson and Foglia in the *embodiment thesis:*

> Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant

[1] This also becomes a methodological issue. It is almost impossible to translate from sign language to written language, even if using lexemes for the notation. Gestures contribute naturally to the interpretation of the utterance such that the analytical distinction between which aspects are signed and which are gestured cannot be made as clear as analytical distinctions between the spoken and the gestured. Neither can be considered separately.

causal role, or a physically constitutive role, in that agent's cognitive processing. (Wilson & Foglia, 2011, paragraph 3)

More precisely, Wilson and Foglia distinguish three roles the body can play in cognition: It can constrain cognition, distribute cognitive processing and regulate cognitive activity (Wilson & Foglia, 2016, paragraph 3). In sum, "such determinate forms of the Embodiment Thesis can ascribe the body either a significant causal role, or a physically constitutive role, in cognition" (Wilson & Foglia, 2016, paragraph 3).

However, the "body as constraint" is not to be understood with a merely negative connotation as one may get at first sight, taking into account two further implications provided by Wilson and Foglia (2016):

- Some forms of cognition will be easier, and will come more naturally, because of an agent's bodily characteristics; likewise, some kinds of cognition will be difficult or even impossible because of the body that a cognitive agent has.
- Cognitive variation is sometimes explained by an appeal to bodily variation. (paragraph 3)

This view on embodied cognition is coherent with the approach taken by Healy and colleagues who understand bodily organs as tools in the sense of Vygotsky, influencing structure and process of thinking (Healy, 2015). As instrumental tools, the sensory organs can be substituted among each other, which "is expected to cause a profound restructuration of the intellect" (p. 299).

Such a substitution comes into play for deaf learners, where the lack of auditive perception becomes substituted by other sensory experiences. In the hearing classroom, information and ideas are shared to a large extent verbally while deaf students acquire information and interact by means of visual modes of expression, just as sign language. Following the theoretical approaches laid out, such a variation concerning the process of learning mathematics should alter cognitive structures and thinking processes, perhaps also leading to differences in conceptualization of mathematical ideas.

Features of sign language

Research in the field of Deaf Studies in fact indicates that deaf people 'think differently' (Grote, 2010, 2013). Grote emphasizes that the modality of language—whether it is communicated in vocal language or in sign language—influences processes of conceptualization. She identifies two features of language modalities with such influences: *Articulation* and *iconicity*.

While information is strung together sequentially and linearly in vocal language, sign language offers the possibility to represent different aspects of the utterance simultaneously. This can compensate for the greater time required by spatial articulation in sign language over that of verbal articulation (Bellugi & Fischer, 1972; Grote, 2013). However, sign language can represent only those concepts simultaneously that stand in a *syntagmatic relationship*, that is, concepts that consist of several aspects connected through linguistic contiguity. Signs that bundle these aspects by using a particular handshape to express additional information are sometimes called *polycomponential signs* (Grote, 2013), *classifier predicates*, or *depicting verbs* (Liddell, 2003). In contrast to this stand the representation of concepts from the same paradigm, e.g. concepts that are connected in hierarchy (see Fig. 1).

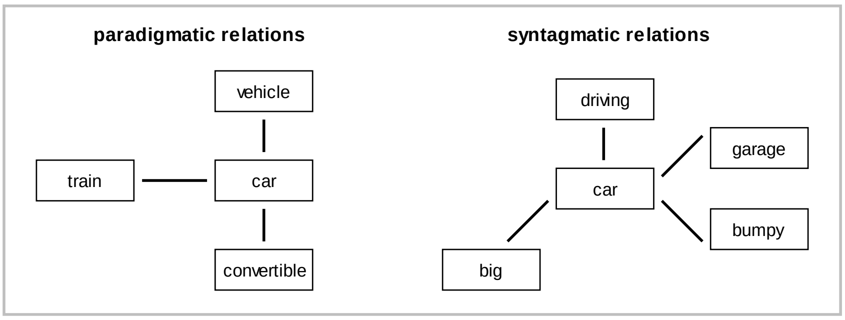

Fig. 1: Example for paradigmatic and syntagmatic relationships (following Grote 2013, p. 313)

These *paradigmatic* (or 'associative' (Saussure, 1983)) relationships need to be articulated linearly, just as in verbal language (Grote, 2010, 2013). Grote (2010) claims that this may lead to a preference for communicating those ideas that stand in a syntagmatic relationship and gives empirical evidence that this preference may engender the establishment of a stronger link between these relations over paradigmatic ones.

Furthermore, gestures often show a certain resemblance with what they signify; they evoke an iconic relation to its referential object. This relationship, however, needs to be established since it is not self-evident. Related to the process of conceptualisation, Grote claims that

> assuming that epistemic processes are processes inherently mediated by signs, the similarity that forms the relationship between icon and referential object is constituted actively. This means that in the process of iconisation, there is a focus on specific features of the semantic concept which probably become stronger linked and get an exposed position in the semantic net. (Grote, 2010, p. 312, translated by the author)

When conducting verification tests, she found remarkably shorter reaction times for those pictures that showed the feature that was iconically reflected in the sign. This pointed to a stronger semantic link between this feature and the signed concept and provided evidence that "those features that are reflected in the iconic moment of sign language get a specific relevance for the whole semantic concept" (Grote, 2010, p. 316, translated by the author).

So what might this mean for the learning of mathematics?

Learning mathematics is not perceived as a purely cognitive phenomenon but can be understood as a social process in which individuals co-construct mathematical meaning and knowledge within the social interaction that is constituted by the use of signs. These signs can be of written, spoken, or gestural form or anything else that can be considered a semiotic sign, performed in any modality. In this sense—and taking into account the embodied approach outlined earlier—learning is understood "as a multimodal process" (Arzarello, 2006, p. 1), influenced by production and perception of signs within social interaction. The use of sign language plays part in both, production and perception.

Based on this, possible issues that can arise are the following:

- A preference of communicating syntagmatic relationships may lead to place special emphasis on these when carrying out social epistemic processes in social interaction and therefore, may lead to make syntagmatic relations conceived as being more important for the related mathematical concept.

- Knowledge about which relations are 'linked' linearly and which simultaneously can influence teaching methods. While in the learning of deaf students there needs to be emphasis on developing paradigmatic inner-mathematical relations, the use of co-speech gestures may support strengthening syntagmatic links also in the regular classroom. Theoretical foundations for such an approach are provided by the results on gestural specification of the verbal utterance in processes of constructing mathematical knowledge in social interaction, as described in Krause (2016).
- Providing 'mathematical signs' as nonverbal terms to students, it needs to be noted that the iconicity of the sign may lead to an exposed position of the aspects that become visually reflected in it. Oftentimes, official and conventionalized 'mathematical signs' do not exist or are not known so that a 'suitable' mathematical sign may develop hand in hand with the knowledge during the learning process in the mathematical classroom (see also Fernandes & Healy, 2014; Krause (2018)). To support the conceptualization of mathematical ideas, it is therefore important to take a closer look at which aspects of a mathematical idea are reflected iconically in a mathematical sign, and how meaning develops in the respective signs in a process of iconization while the ideas become encountered. Within this process, the iconicity of the gesture may inform about the signer's current conceptionalization of the mathematical idea. This may be used for the purpose of assessment and fits the development of the 'associated gestures' found in hearing learners' social processes of constructing mathematical processes (Krause, 2016).
- Many mathematical concepts are shaped metaphorically so that the mathematical concepts are understood through something familiar or more illustrative (Lakoff & Núñez, 2000). These metaphors cannot be represented iconically in a direct way, the developing sign/gesture rather refers to an 'underlying' meaning (see again Fernandes & Healy, 2014). Gestures developed by deaf students while constructing mathematical knowledge in social interaction may therefore indicate possible approaches to these ideas and concepts. Knowledge about these approaches can also help in cases of learning mathematics in a second language since linguistic approaches to metaphors may not be accessible.

The research program "DeafMath"

These considerations motivate my research program in which I investigate the influence of sign language on the conceptualization of mathematical ideas, focusing on two main aims:

- Contributing to the development and further elaboration of a theory on the role of the body in the conceptualization of mathematical ideas,
- Providing theoretical foundations for developing didactical methods and strategies that involve the body in processes of teaching and learning.

Furthermore, another goal lies in the development and evaluation of methodological approaches that take into account the specificity of the research setting when working with deaf children. The crucially different characteristics of sign language as a visual-gestural language, as well as the students' difficulties with written language, demand an adaption of methods for collecting, preparing, and analysing data. This becomes especially important with respect to qualitative studies that follow interpretative and reconstructive methods since the holistic representation in sign language cannot be captured merely in written form that can only reflect linear and segmented language. A (more) suitable methodological approach might place a greater emphasis on the coordination of written transcripts, pictures, and videos for means of analysis, but also for the documentation of the results.

Potential long-term goals with respect to implications on teaching methods and strategies concern the following aspects:

- The identification of challenges that are specific to deaf students and countering them in their core: Is one challenge grounded in their understanding of (some) mathematical concepts as deviating due to the deviating modality of their language?
- Understanding the inclusion of deaf learners and their way of communicating as actual surplus in the inclusive classroom. Results gained from these studies can point out how an actual inclusion of hearing-impaired students can enrich the entire classroom.
- Using representational gestures in a goal-directed way as didactic means. In Krause (2016) I describe how the use of representational gestures can influence the collective formation of mathematical concepts in a beneficial way by its various representational functions. Results derived from the here described study may give insights in how these representational gestures may look like.

This program therefore considers ‘barriers and chances’: While the different kind of communication may lead to specific challenges when learning mathematics, taking into account these differences entailed by the spatial-visual-somatic and embodied medium of sign language might help to “become better able to respond to their particular needs, but also build more robust understandings of the relationships between experience and cognition more generally” (Healy, 2015, p. 289).

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